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Development of Line Load Apparatus and Exploratory Studies in the Behaviour Plywood Box Beams

by
M.S. Dubas

Thesis
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#6

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ABSTRACT

An apparatus employing a pneumatic tube and capable of delivering a uniformly distributed reactive-type load over a 20 foot span was designed for 5000 pounds per lineal foot and tested to 27% of its design range. Two 20 foot plywood box beams were fabricated and exploratory investigations with respect to their behaviour in flexure were made simultaneously with the testing of the apparatus.

A uniformly distributed load of 1375 pounds per lineal foot (200% of the design load of the plywood beams) was obtained. The loads on the beams were uniformly distributed when the volume of the pneumatic tube was less than its maximum unstretched volume. The loads were measured with calibrated steel reaction rods with a maximum error of 2% at maximum loads and the apparatus maintained these loads for a good length of time. Modifications to the tube chamber in the apparatus were made during the tests and further modification would be necessary to protect the tube.

In most tests the plywood beams were loaded to approximately 150% of their design load and strains were observed at midspan, in the area of the web splice and in the area where surface shrinkage cracks had developed. A comparison was made between the strain readings obtained using SR-4, Type A-3, electric strain gages and 0.0001" mechanical dials on 8" gage lengths. Midspan beam deflections were observed.

The differential shrinkage between solid Douglas-fir and Douglas-fir plywood caused a variation of strain up to 40% (at design load) across the flanges of the beams. Strains in the vicinity of the web splice were as much as 25% greater than theoretical. The strains measured with the SR-4 gages compared favourably with those measured with the mechanical dials. Midspan beam deflections were 3.3% and 10.7% less than the calculated deflections.

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#6

THE UNIVERSITY OF ALBERTA

DEVELOPMENT OF LINE LOAD APPARATUS
AND
EXPLORATORY STUDIES IN THE BEHAVIOUR PLYWOOD BOX BEAMS

A DISSERTATION

SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES

IN PARTIAL FULFILMENT OF THE REQUIREMENTS OF THE DEGREE

OF MASTER OF SCIENCE

FACULTY OF ENGINEERING

DEPARTMENT OF CIVIL ENGINEERING

by

M. S. Dubas

under the direction

of

J. Longworth

EDMONTON, ALBERTA

September, 1955

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PREFACE

The following study is presented in two parts, namely, Part I, "Development of Line Load Apparatus", and Part II, "Exploratory Studies in the Behaviour of Plywood Box Beams". Although one forms an integral part of the other it is necessary to establish the validity of the first in order to gain a true perspective of the latter. Accordingly, Part I deals with the loads used and Part II deals with the effects of these loads.

M. S. D.

EDMONTON,
September, 1955.

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PART I

DEVELOPMENT OF LINE LOAD APPARATUS

PART I

I Introduction

Today most structural materials testing laboratories are equipped with beam testing apparatus that will subject specimens to relatively concentrated loads. When the necessity for testing under uniformly distributed load arises, little in the way of equipment is available and recourse is taken to cumbersome and sometimes costly means of gravity loading. In view of this the present study was undertaken to determine the possibility of obtaining a uniformly distributed line load in a form that would be economical and could conveniently be used in laboratory testing.

Pneumatic pressure has been used as a means of distributing load - notably in the automobile tire. If the tire were made of a very flexible material, the load being distributed would be approximately equal to the product of the pressure within the tire and the area of roadway on which the tire was brought to bear. Thus, with the area of the bearing surface and internal pressure of the tire known, the distributed load could be computed. Consider a long pneumatic tube confined within an equally long box of rectangular cross-section with one side movable. Furthermore, assume that the pressure contained in the pneumatic tube is transmitted directly and practically unaffected (minor losses due to friction) to the walls of the box which restrains it. The load on the movable side of the box can then be expressed in the form

$$W_e = KpA$$

where

W_e = total experimental load capacity in pounds of the apparatus,

p = gage pressure in pounds per square inch,

A = area on which the load is acting in square inches,

K = an experimental constant.

The intensity of loading per unit length may be expressed as

$$w_e = \frac{KpA}{L}$$

where

w_e = experimental intensity of load in pounds per lineal foot,

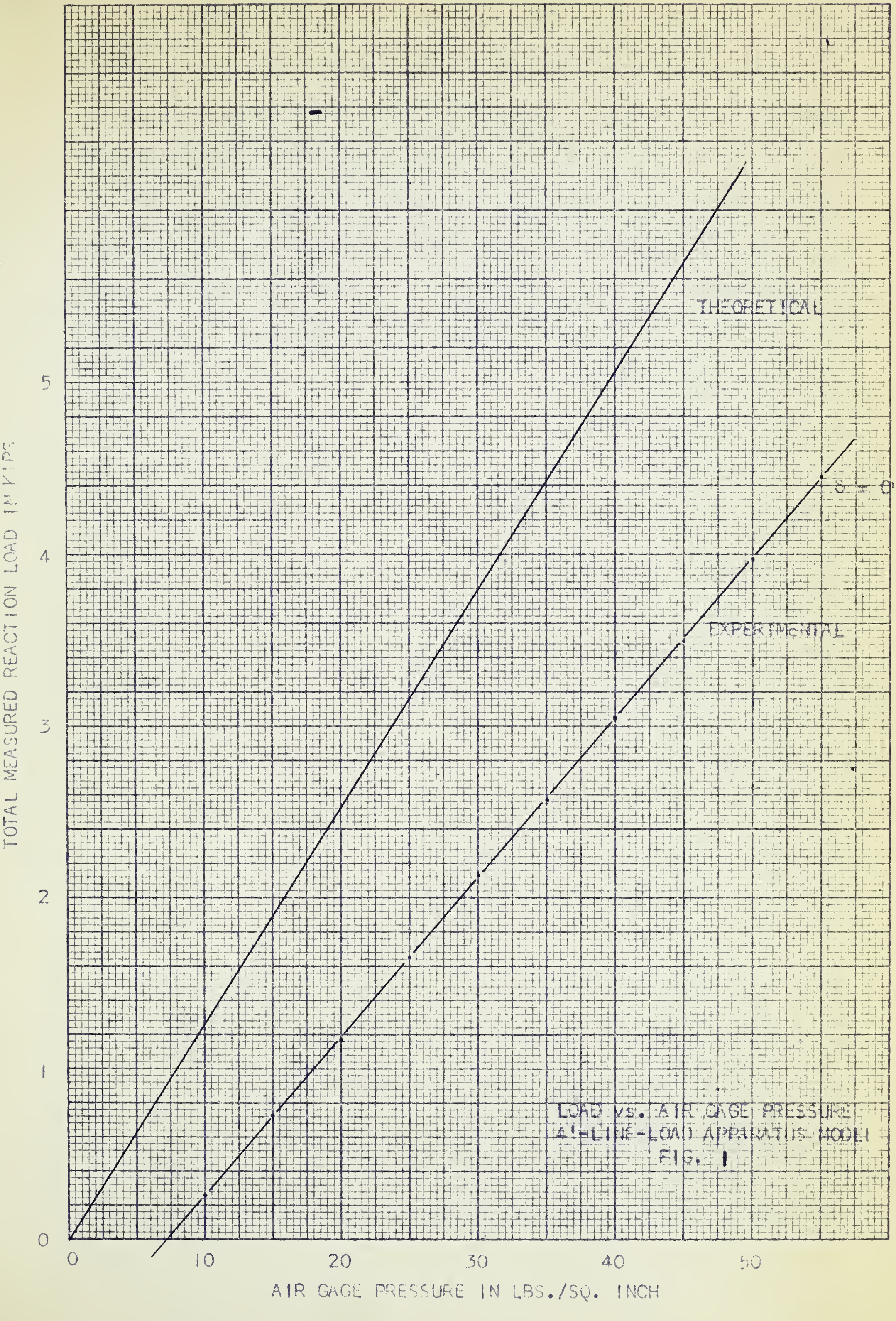
L = length of the elongated area in feet.

Since the pressure is constant over the area and the width of the area is a constant, an empirical relationship between the load and the pressure in a linear form indicates that the load is uniformly distributed.

In order to check the validity of the above, a preliminary model study was undertaken. The model consisted of a wooden chamber 2 5/8" wide, 48" long and approximately 2" deep with ends sealed and backed by a 3" x 10" fir plank 48" long. A standard 28" x 1 1/2" bicycle tube cut 48" long with ends vulcanized was used as the pressure tube. Minor protection was afforded the tube from the sharp corners of the tube chamber and a series of distribution blocks similar to those described in the prototype later, was used. An uncalibrated tire gage was used to measure pressure. The test can be considered as a static one since in the process of loading the volume of the tube was held constant. The model was placed on the table of the 200,000 pound Baldwin testing machine (0 - 10,000 pound range used), pressure was applied to the tube and the total load measured. The results of this test are plotted in figure 1.

The results of the model test demonstrated a linear load-pressure relationship. The slope of the experimental line was less than the theoretical and the line did not pass through the inter-

section of the co-ordinate axes. The latter was attributed to necessary initial inflation pressures, the lifting of the dead weight of the apparatus and friction. In using this simplified model it was impossible to determine the effect on the load-pressure relationship of varying the pneumatic tube volume.



LOAD VS. AIR GAGE PRESSURE
4"-LINE-LOAD APPARATUS MODEL I
FIG. 1

II Scope

The object of this study was to obtain experimental data on the feasibility of obtaining a uniformly distributed and measurable line load from an apparatus activated by pneumatic pressure and loads measured with calibrated steel rods.

The apparatus and 2 plywood box beams were designed and fabricated and the load-pressure relationships of the apparatus were observed. Modifications to the apparatus were later introduced and the load-pressure relationships were again observed.

III Design of Apparatus

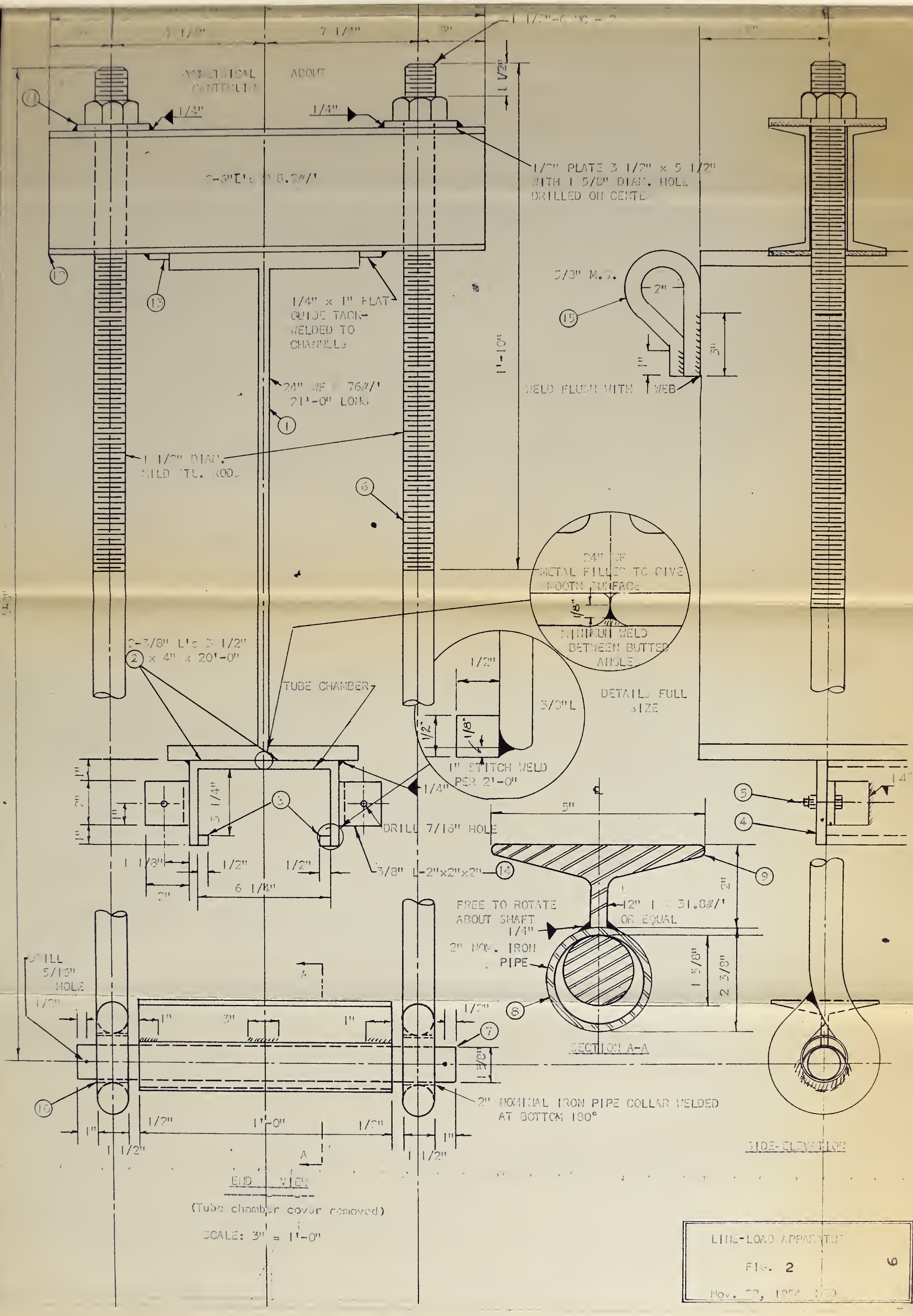
The prototype was designed to deliver a uniformly distributed load of 5000 pounds per lineal foot over a 20'-0" span. Load was applied by forcing air into the pneumatic tube and was measured by the strains in the calibrated reaction rods. Construction details are shown in figures 2, 3 and 4 and photographs of the assembly used in the testing program are shown in figures 5 and 6. The apparatus consisted of a 21'-0" long wide flange steel beam with a 20'-0" long tube chamber rectangular in cross-section and built of structural angles welded to the face of one flange of the beam. Added to this were two pairs of reaction rods. These rods were provided with channel frames for bearing against the flange of the WF-section and split I-section frames pivoted on shafts passing through the eyes of the reaction rods for bearing against the beam being tested. A 20'-0" long tube connected to an auxilliary air reservoir was used as the pneumatic pressure mechanism. The auxilliary air reservoir shown in figure 6 was connected to the pneumatic tube to increase the total volume of air used. This was done to reduce the effect of tube volume increase and consequent load drop due to yielding of a beam in the process of being tested near its ultimate load. Distribution of load from the pneumatic tube to the beam being tested was obtained by using a 20'-0" length of linked 3" wooden blocks. Two 24" deep, 20'-0" span, plywood box beams each designed to carry a live load of 675 pounds per lineal foot were used to test the apparatus. The construction and material specifications for these beams are shown in Part II.

A variety of materials were used in fabricating the apparatus. The structural steel shapes were of A. S. T. M., A7, Bridge steel. Shaft steel was used for the bearing plate pivots. An old metal

hot water tank with an approximate capacity of 4 cubic feet was used as the auxilliary air reservoir. This tank was subjected to an air pressure test of 35 pounds per square inch for a short duration of time without showing leakage. The requirements for the fabrication of the pneumatic tube are shown in figure 3. The method of fabrication was not specified since it was thought better to permit the fabricator to proceed as his equipment permitted. The pneumatic tube was vulcanized of tube rubber and connections between the tube, the air reservoir and air supply were made with 1/8" Saran tubing employing flare fittings. It was necessary to machine a fitting for the valve on the tube. A standard automobile tube-type valve was fitted to the air reservoir at which point the air pressure was applied. Pneumatic pressure in excess of 80 pounds per square inch was supplied by the University Power Plant. 8 gage canvas duck was used for the tube protector and linkage mechanism in the distribution blocks. The distribution blocks were made from a 4" x 8" Douglas-fir plank selected for grain and minimum checks and knots. The main steel structure and pneumatic tube were supplied by local fabricators.

Steel members in the apparatus were designed in accordance with A. I. S. C. specifications. From the results in the preliminary model study it was assumed that an air pressure 30% in excess of theoretical would be required to produce design load. Since the maximum design bending stress in the compression flange of the WF-beam was approximately 15000 pounds per square inch, no lateral support of this flange was provided. Two sets of reaction rods were designed: a set of 1 1/2" diameter rods for use with the apparatus when at full capacity; and another set of 3/4" diameter rods which were stressed to the permissible working stress in

tension when one of the plywood test beams was subjected to 200% of its design load.



END VIEW

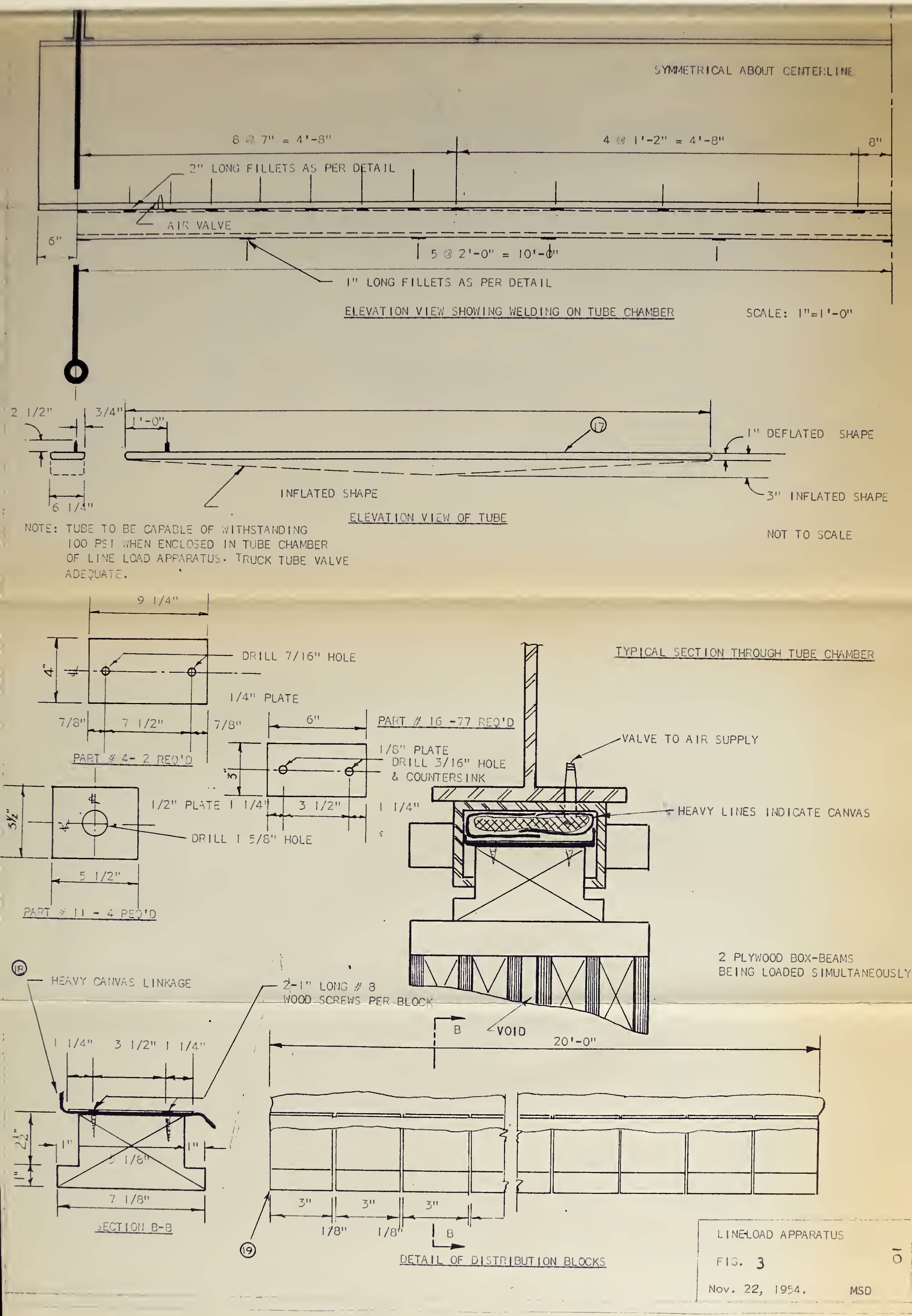
(Tube chamber cover removed)

SCALE: 3" = 1'-0"

LINE-LOAD APPARATUS

FIG. 2

Nov. 23, 1954 [illegible]



NOTE: TUBE TO BE CAPABLE OF WITHSTANDING
100 PSI WHEN ENCLOSED IN TUBE CHAMBER
OF LINE LOAD APPARATUS. TRUCK TUBE VALVE
ADEQUATE.

LINELOAD APPARATUS
FIG. 3
Nov. 22, 1954. MSD

SUMMARY OF MATERIALS REQUIRED FOR LINE-LOAD APPARATUS

MARK	QUANTITY	DESCRIPTION
1	1	24" WF @ 76#/' - 21'-0" LG.
2	2	3/8" x 3 1/2" x 4" L's - 20'-0" LG..
3	2	1/2" SQ. - 20'-0" LG.
4	2	1/4" x 4" x 11" FLAT AS PER DETAIL
5	4	3/8" x 1 1/2" MACHINE BOLTS WITH NUTS
6	4	EYE-BOLTS, THREADED, WITH COMMENSURATE NUTS, AND AS PER DETAIL
6a	4	(NOT SHOWN) AS MARK 6 ONLY 3/4" DIAMETER RODS
7	2	1 5/8" DIAMETER RODS - 1'-6" LG.
8	2	2" NOMINAL DIAMETER STANDARD IRON PIPE 1'-0" LG.
9	2	12" LG. T-SECTION EQUAL TO TOP OF 12" I @ 31.8#/'
10	2	2" NOMINAL DIAMETER STANDARD IRON PIPE - 1 1/2" LG.
11	4	1/2" PLATE 3 1/2" x 5 1/2" WITH HOLE AS PER DETAIL
12	4	6" CHANNELS @ 8.2#/' - 1'-8 1/2" LG.
13	4	1/4" x 1" x 5 1/2" FLAT
14	4	3/8" x 2" x 2" x 2" L's WITH HOLES AS PER DETAIL
15	2	5/8" ROUND ROD HOOKS AS PER DETAIL
16	77	1/8" FLATS 3" x 6" WITH HOLES AS PER DETAIL
17	1	20'-0" LG. RUBBER TUBE AS PER DETAIL
18	1	7 yds. x 26" HEAVY CANVAS STRIP (8 ga.)
19	1	4" x 8" x 20'-0" FIR PLANK
20	160	1" LG. #8 WOOD SCREWS

FIGURE 4

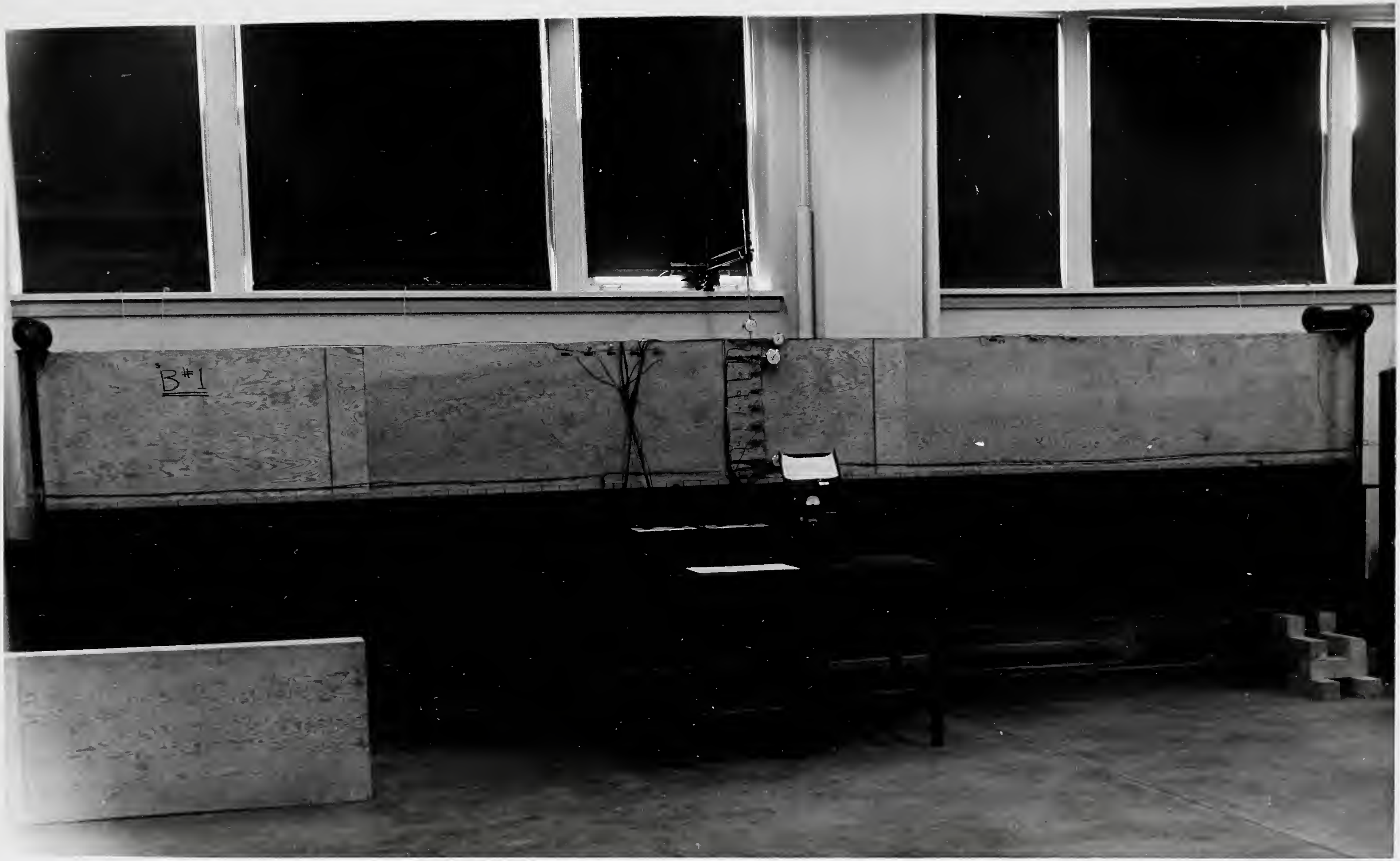


Fig. 5, Elevation View of Line-Load Apparatus With Beam # 1 in Loading Position.

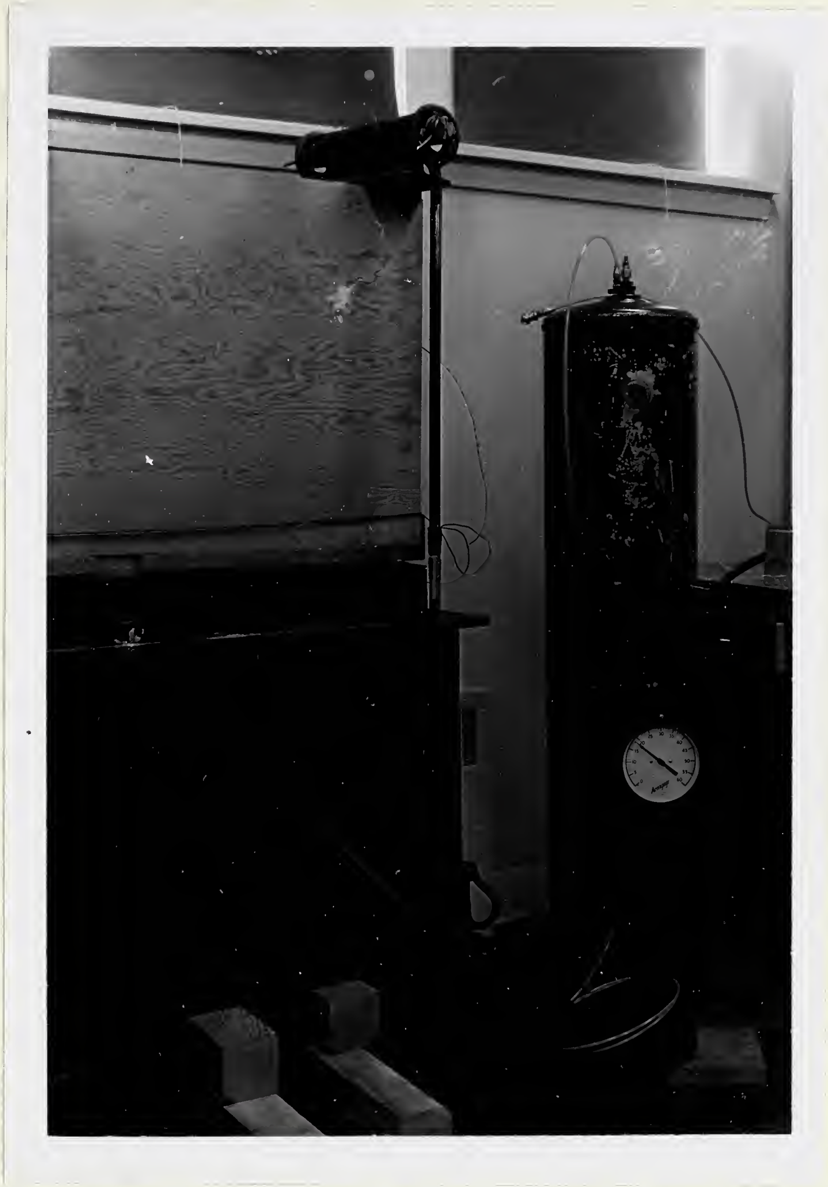


Fig. 6, Elevation View of End of Line Load
Apparatus and Air Reservoir.

IV Experimental Procedure

1. Instrumentation

Steel strains in the reaction rods were measured with SR-4, Type A-3, Baldwin - Southwark electric strain gages. These were applied according to manufacturer's specifications and also checked for electrical non-conductivity between their leads and the material on which they were placed. Strains were read on a Baldwin Type L Strain Indicator.

Air pressures were measured with an "Acragage", 0 - 60 pounds per square inch range air gage graduated in 0.5 pounds per square inch intervals. This gage was checked at 5 pound per square inch increments on a dead weight tester and found to read as graduated.

The beam deflections at midspan were measured with a 0.001 inch Ames dial.

Load on the beams tested was determined by measuring the calibrated strains in the reaction rods. The 3/4" diameter reaction rods were used in most of the tests. These rods were double-gaged (wired in series), the strain gages being applied at approximately mid-length, diametrically opposite one another, parallel to the longtitudinal axis and perpendicular to the plane of the eye of each rod. These are shown in the photograph of figure 6.

Calibration of the strain gages was done in the 200,000 pound Baldwin hydraulic testing machine with the 0 - 10,000 pound range being used. Each rod was fixed in the top crosshead by passing a 1 3/4" round bar through the eye and was allowed to hang vertically after which the bottom was fixed to the lower crosshead by means of a nut and large washer. The nut was hand turned into position. Every attempt was made to simulate the conditions of restraint

occurring in the actual beam test. The rods were then loaded and the strains measured for 250 and 500 pound increments with a constant record of the strains being kept. It was necessary to pull the rods to 7000 pounds a minimum of 3 times before the recorded strains repeated themselves. The strains recorded for loading and unloading differed only by a maximum of 5 microinches per inch. The resulting load-strain relationships are shown in figures 7, 8, 9 and 10. The following tabulation indicates both the modulus of elasticity determined and degree of refinement of the calibration.

Rod No.	Area of Rod at Gage Point in sq. ins.	Modulus of Elasticity lbs./sq. in.	Discrepancy in Strain Readings microinches/inch
1	0.428*	30.2×10^6	+ 2**
2	0.428	30.2 "	- 4
3	0.428	29.6 "	± 3
4	0.430	29.8 "	± 2

* The points at which the gages were fixed were not machined to size, but hand-sanded and consequently an average diameter was used for each in the calculations.

** The tabulated strain discrepancy is the average difference between loading and unloading strains for the same loadings for 12 or more readings.

Originally the 1 1/2" diameter reaction rods were calibrated using single gages placed at mid-length along the rods, parallel to the longtitudinal axes and parallel to the planes of the eyes. The plywood beams had warped slightly from drying and proper bearing of the transverse shafts through the eyes of the rods was not obtained. As a result some strain readings were negative for small loads. This factor combined with the additional advantage offered by the use of smaller rods led to the use of the 3/4" diameter rods.

The strains for the same loads using the 3/4" diameter rods were four times greater offering a greater precision of measurement. These rods were originally calibrated using single gages with

the gages placed in the plane perpendicular to the plane of the eye of the rods. The data obtained is shown in figures 11, 12, 13 and 14. The difference in slope of these plots was found to be consistent with the measurable eccentricity of the eyes of the rods, particularly in rod No. 3 where the eccentricity was 5/16". This complication eventually led to double-gaging the rods.

2. Testing Procedure

All the testing was conducted in the Structural Analysis Laboratory of the Engineering Building where the temperature was fairly constant at about 70°F. The apparatus was oriented in a north-south direction with the air valve at the north end. Reaction rods Nos. 1 and 2 were placed at the south end and Nos. 3 and 4 at the north end of the apparatus. For convenience the apparatus was inverted as shown in figures 5 and 6. The beams were placed either singly or together on top of the load distribution blocks, the valve to the air reservoir being removed so that the tube was completely deflated. In the case of the double beam loadings, 2" x 4" wooden "load spreaders" were used so that the load would be applied directly to the full face of the two beams. The reaction rods were allowed to hang vertically and then the nuts on the ends were hand tightened bringing the channel frames in contact with the flange of the WF-beam.

Air was then introduced into the air reservoir and the load, as measured by the strain gages, was increased in increments of approximately 1/4 design load (13,800 pounds = total design load). After the application of each increment of load, sufficient time was allowed to elapse to give steady readings on the strain recorder. In the longer intervals between loading, readings of gage pressure (estimated to 0.1 pounds per square inch) and load were taken

at the beginning and at the end of the intervals. Generally, the beams were unloaded gradually. Deflections of the beams were measured at midspan.

General observations made during the process of testing led to some modifications to the tube chamber which were made and tested. The time interval between increments of load was reduced when no change in load was observed 2 to 3 minutes after application of air pressure. During the first 2 minutes after application of air pressure the movement of the air through the tube connecting the air reservoir and the pneumatic tube was audible. Some difficulty was encountered with the switch on the strain recorder and the resulting data which was useful in part, is either presented here or in part II.

The following tabulation indicates the procedure used in the individual tests of significance in the performance of the apparatus. Each individual test is denoted symbolically, for example, B2 S2, refers to the second cycle or series of readings for the loading and unloading of beam No. 2.

B1 S2 - Loads were applied in intervals up to 40 minutes to a maximum of 150% of design. This was the only test in which the single-gaged 3/4" diameter reaction rods were used.

B1 S3 - The inverted beam was loaded to 150% of design and the load was left on for 15 hours. Strain indicator readings displayed some inconsistency necessitating repairs to the indicator.

B1 S5, B1 S6 - Loads were applied in intervals of 2 to 4 minutes to a maximum of 150% of design.

B1 S7 - Loads were applied in intervals of 2 to 4 minutes to 15,600 pounds. Air was released from the air reservoir until the load fell to 8,600 pounds and then the beam was reloaded to 150% of design.

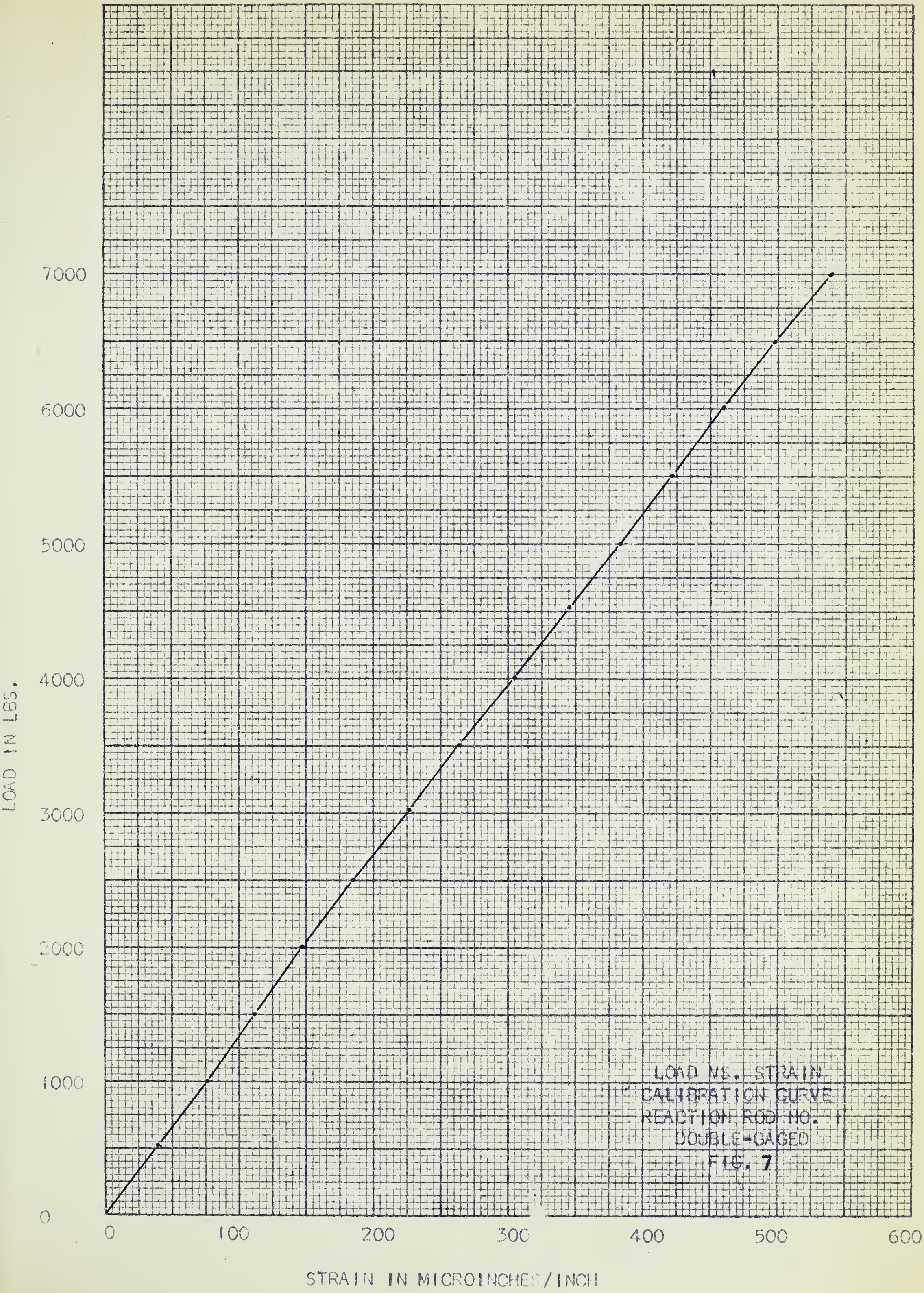
B2 S2 - Loads were applied in intervals of 15 minutes to 150% of design.

B2 S3, B2 S4 - Loads were applied in intervals of 2 to 3 minutes to 150% of design.

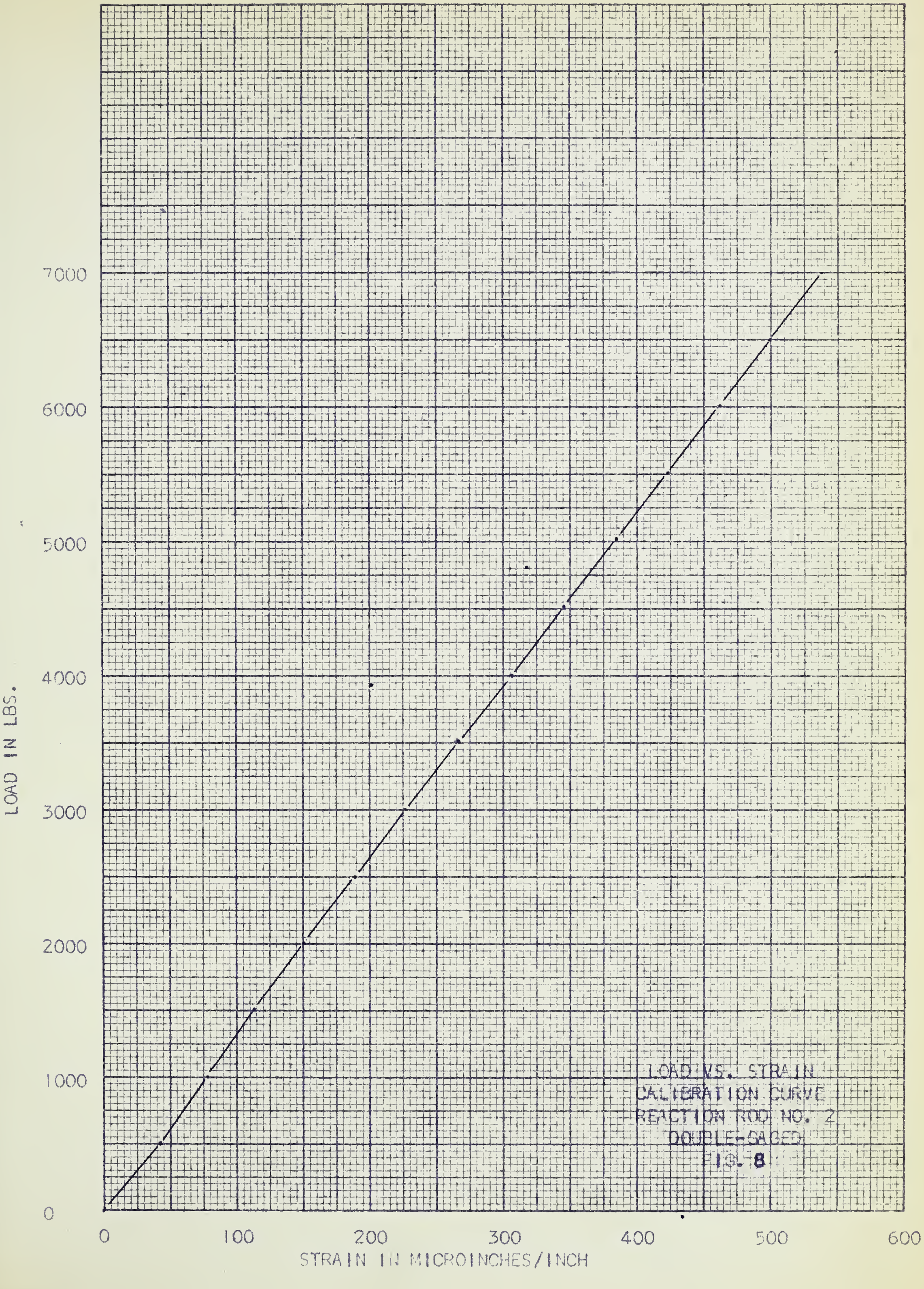
B1 S8 & B2 S6, B1 S9 & B2 S7 - The beams were loaded in pairs with the loads being applied in 2 to 5 minute intervals to a maximum of 100% design load for each beam. The more linear load-pressure plot obtained from these tests led to modifying the tube chamber.

B2 S8 - The tube chamber was modified to that shown in figure 26(b) and the beam was loaded in 2 to 3 minute intervals to 200% of design. A leak developed in the tube which led to another tube chamber modification.

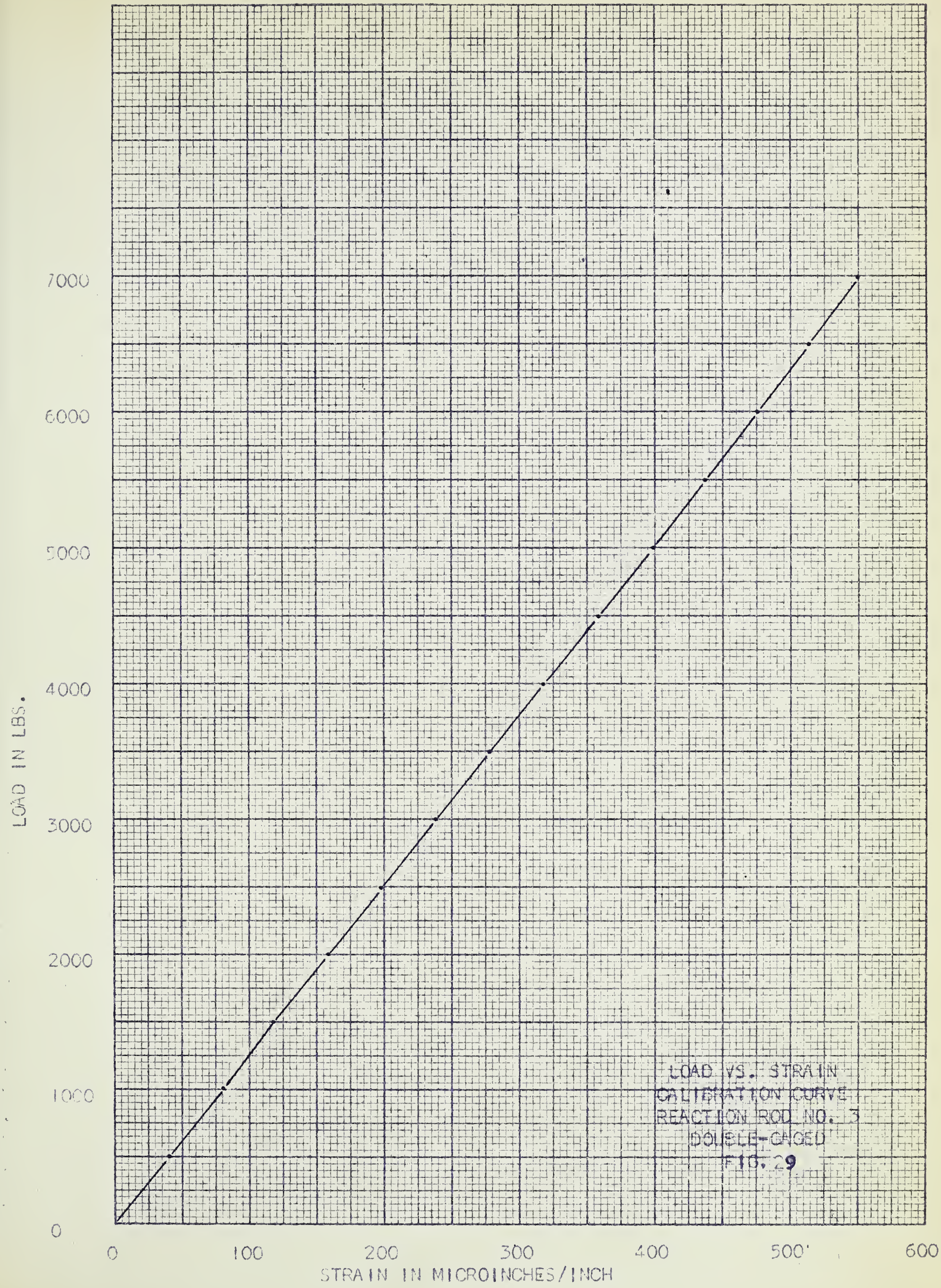
B2 S9 - The tube chamber was modified to that of figure 26(c). A 12" cut developed in the tube at approximately 50% of design load and this data was discarded .



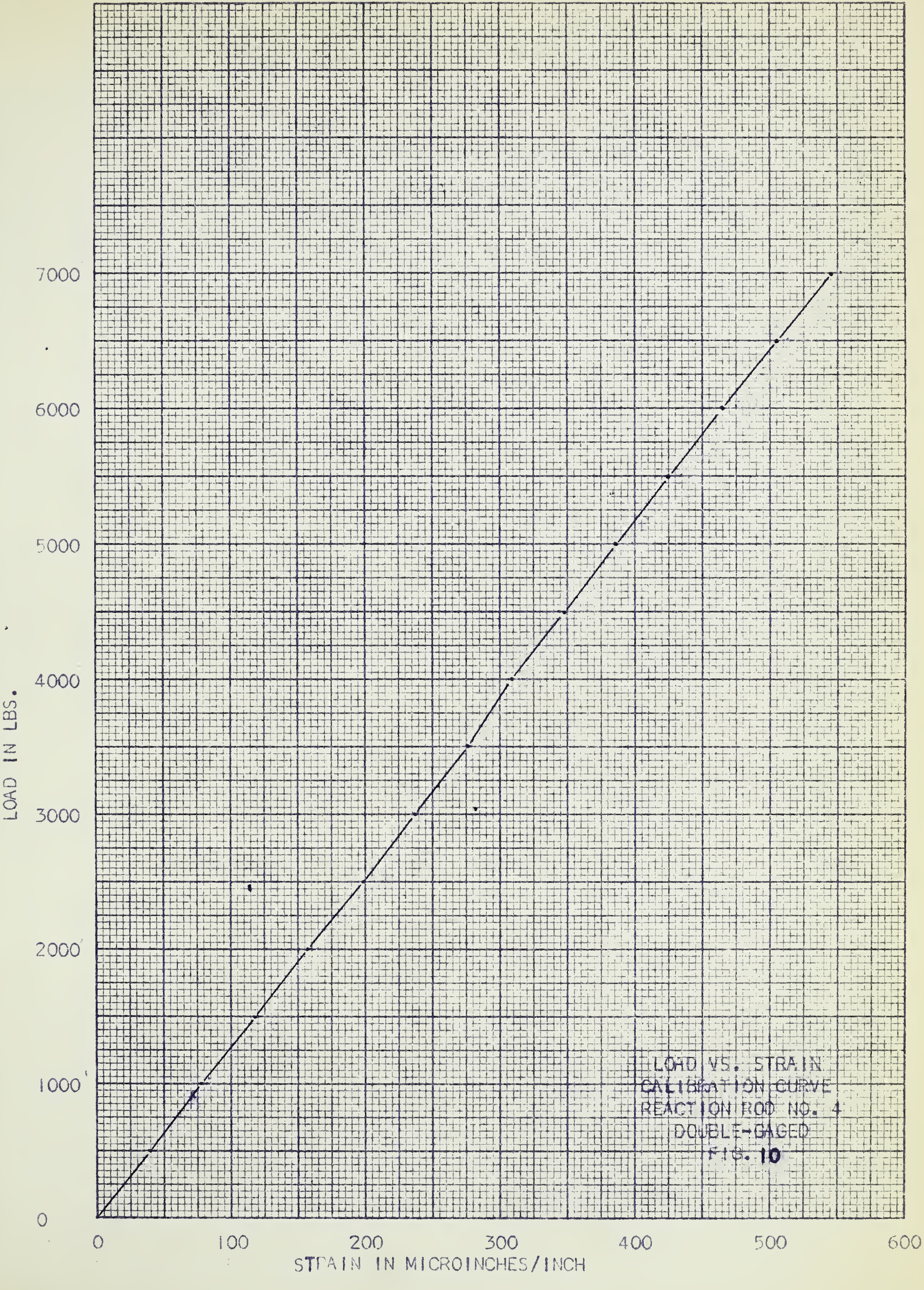
LOAD VS. STRAIN
CALIBRATION CURVE
REACTION ROD NO. 1
DOUBLE-GAGED
FIG. 7



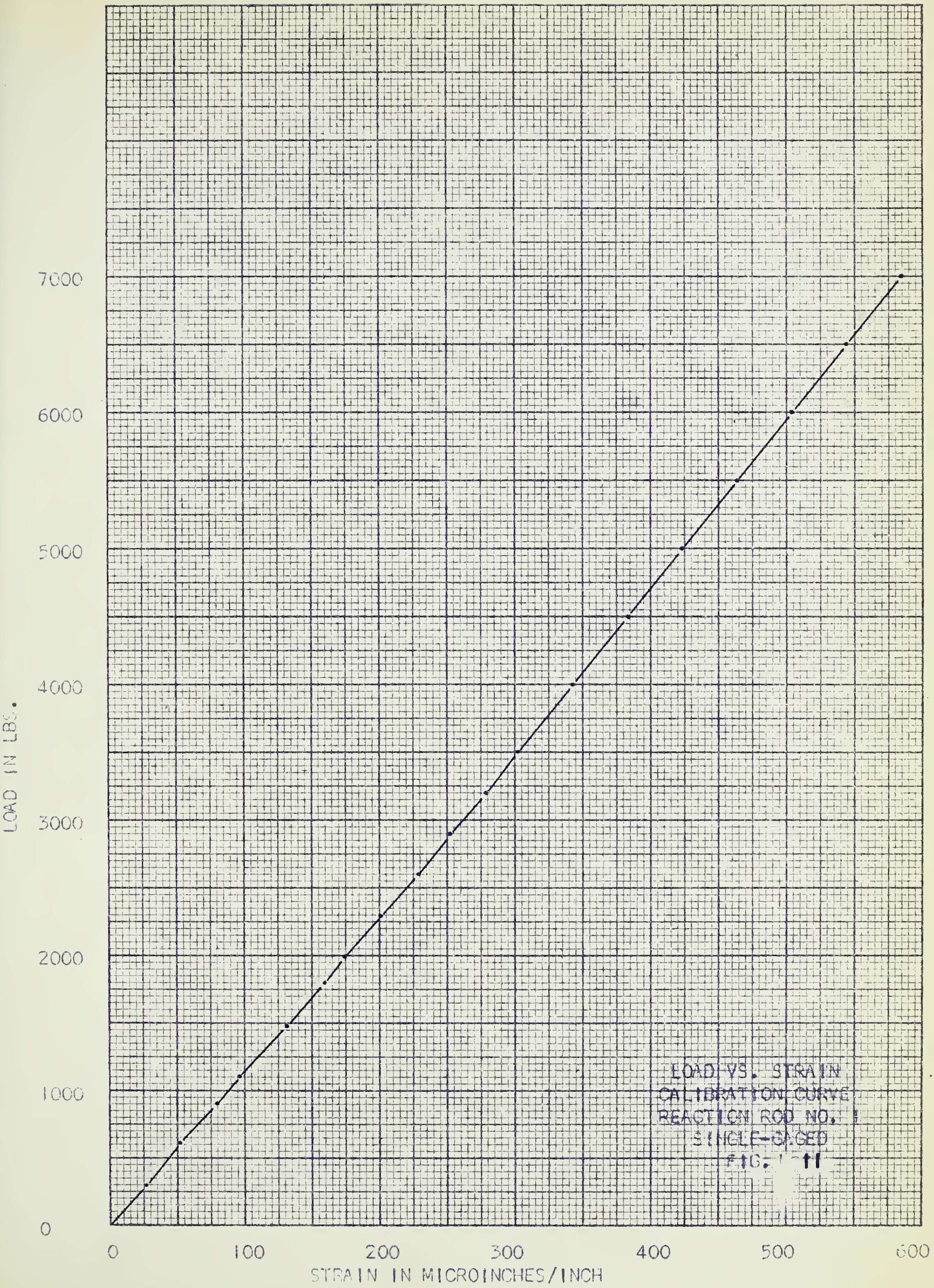
LOAD VS. STRAIN
CALIBRATION CURVE
REACTION ROD NO. 2
DOUBLE-GAGED
FIG. 8



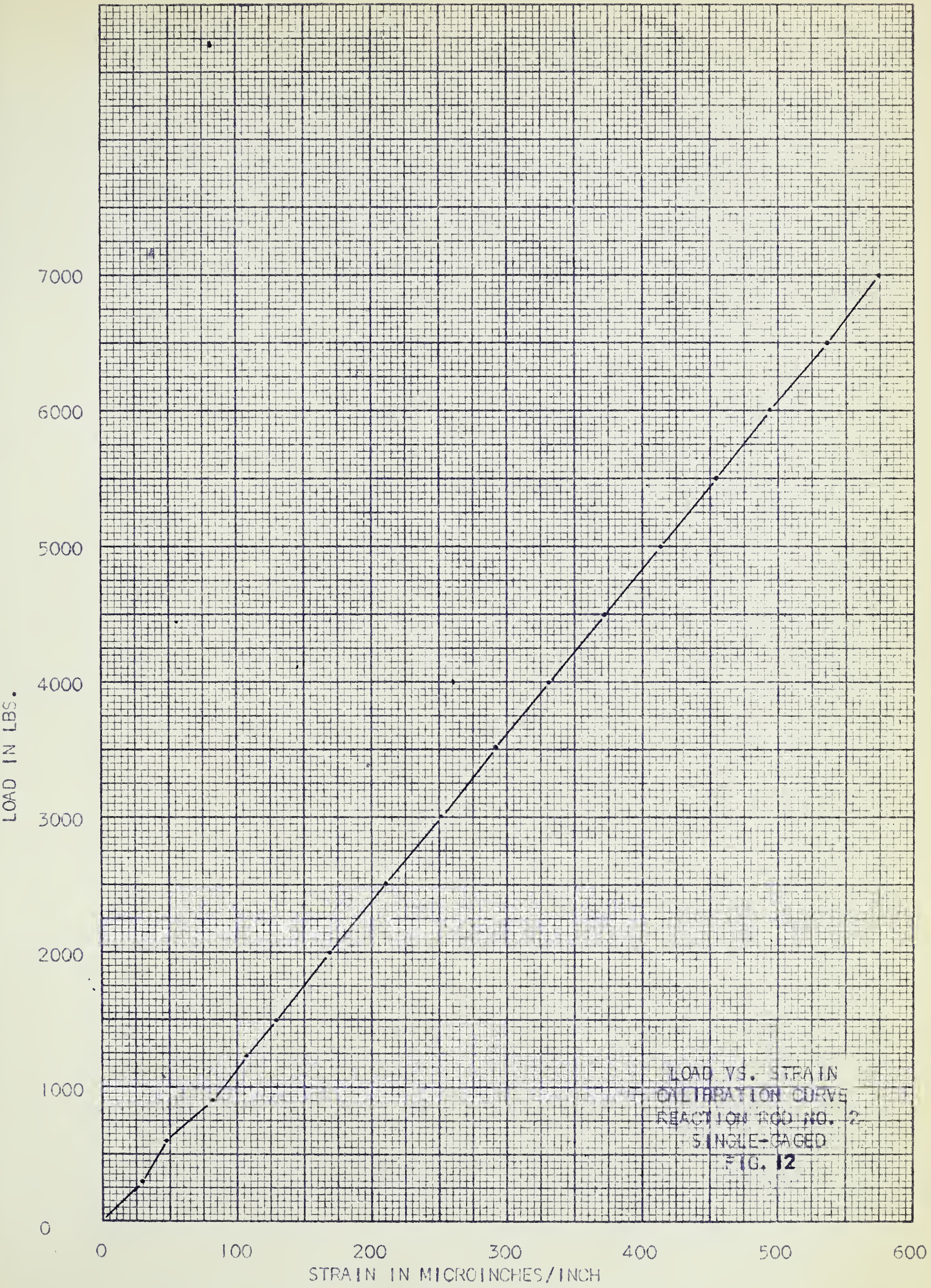
LOAD VS. STRAIN
CALIBRATION CURVE
REACTION ROD NO. 3
DOUBLE-GAGED
FIG. 29



LOAD VS. STRAIN
CALIBRATION CURVE
REACTION ROD NO. 4
DOUBLE-GAGED
FIG. 10

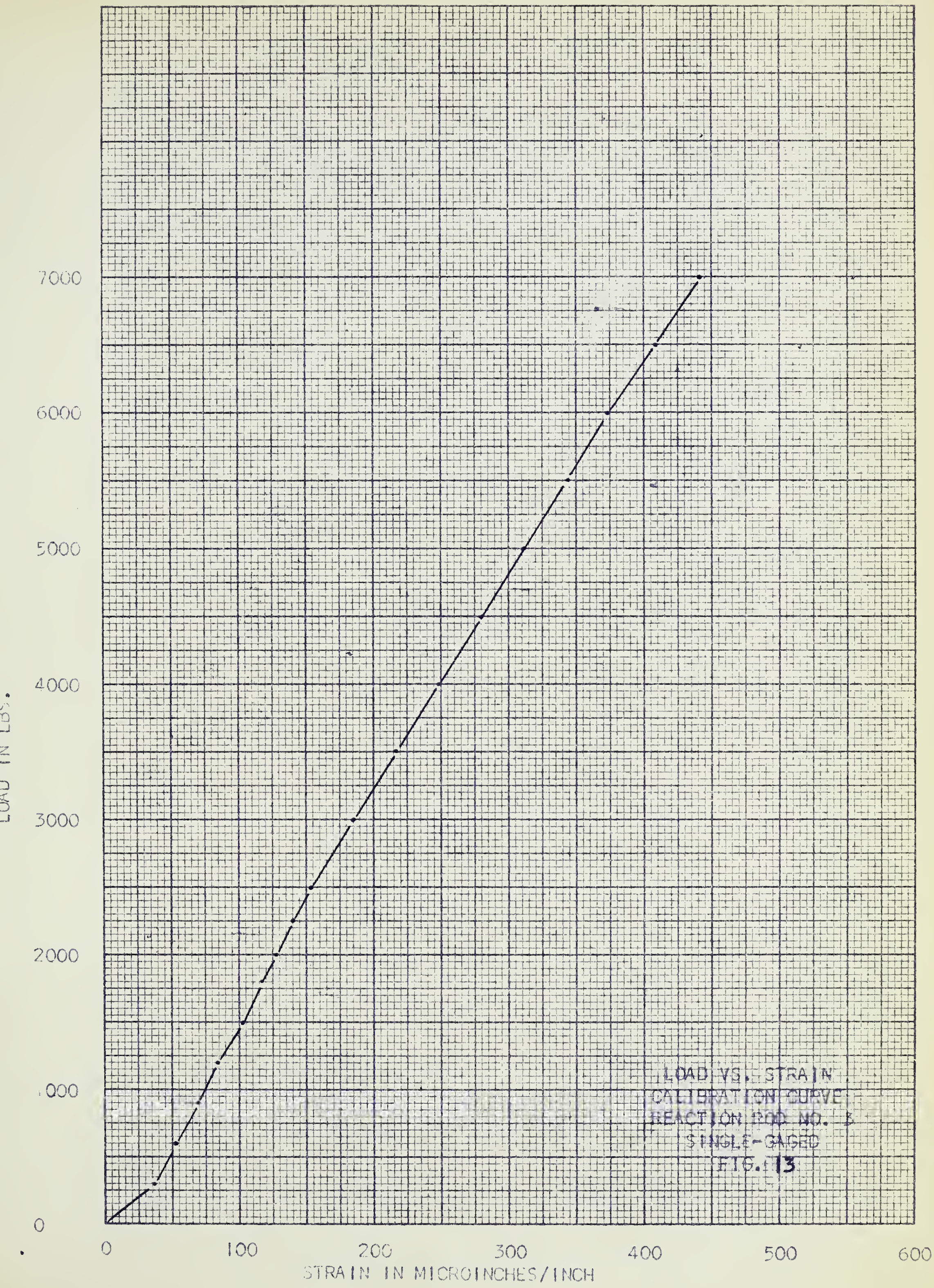


LOAD VS. STRAIN
CALIBRATION CURVE
REACTION ROD NO. 1
SINGLE-GAGED
FIG. 11

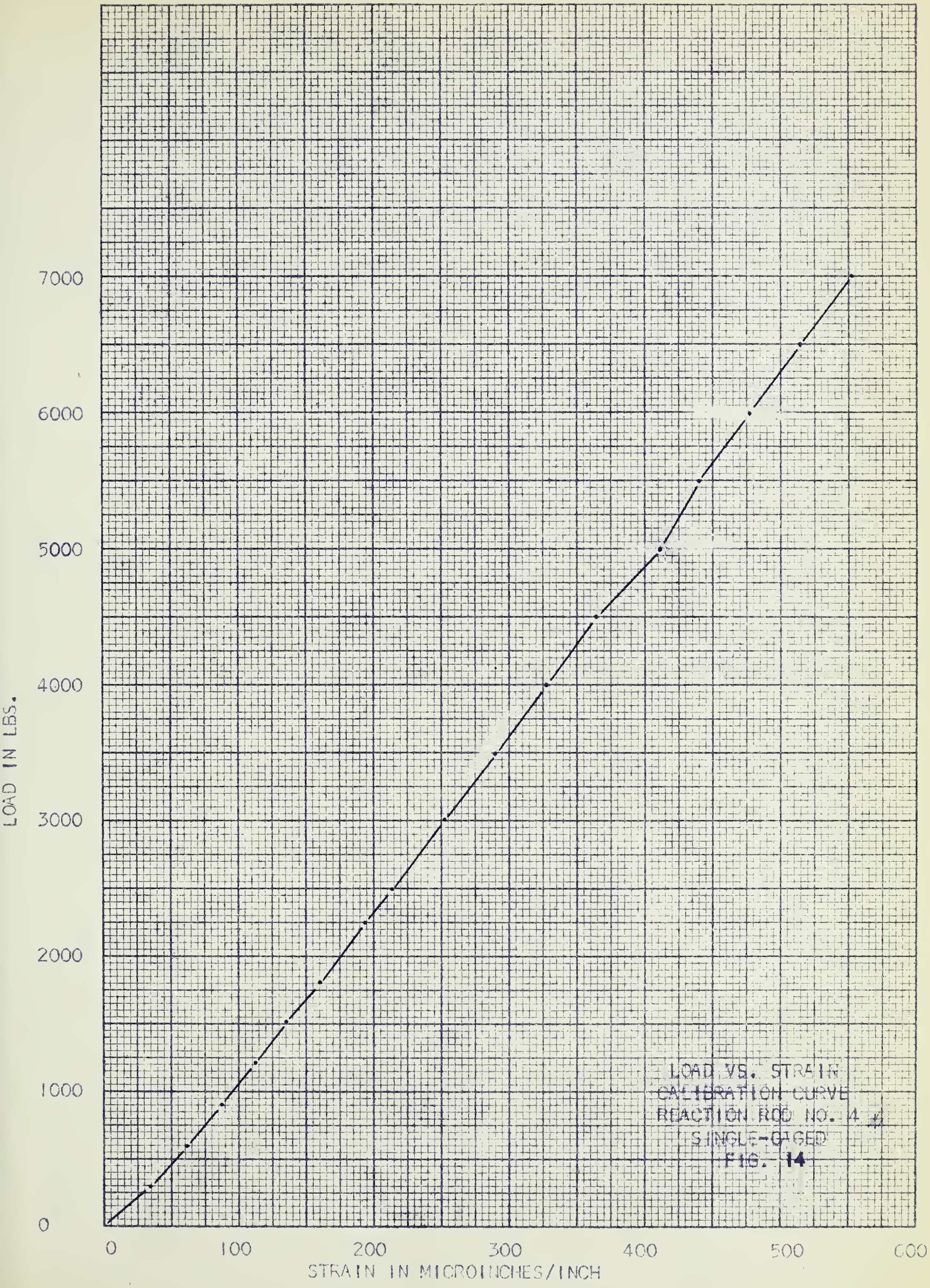


LOAD VS. STRAIN
CALIBRATION CURVE
REACTION ROD NO. 2
SINGLE-GAGED

FIG. 12



LOAD VS. STRAIN
CALIBRATION CURVE
REACTION ROD NO. 3
SINGLE-GAGED
FIG. 13



LOAD VS. STRAIN
CALIBRATION CURVE
REACTION ROD NO. 4
SINGLE-GAGED
FIG. 14

V Presentation of Results

The major portion of the data is presented graphically in plots of total measured reaction versus air gage pressure. These data for loadings B2 S2, B2 S3, B2 S4, B1 S5, B1 S6, B1 S7, B1 S8 & B2 S6, B1 S9 & B2 S7 and B2 S8 are shown in figures 15 to 18 inclusive. Figures 19 to 22 are corresponding plots of the individual end reactions versus air gage pressure. A plot of the midspan deflection of beam No. 2 versus air gage pressure for cycle B2 S2 is shown in figure 23.

Additional significant observations particular to certain cycles of loading are listed below.

B1 S2 - The load was held at 125% of design for 40 minutes without any measurable drop in air pressure.

B1 S3 - For the beam loaded to 150% of design a drop in air gage pressure of 0.1 pounds per square inch over a period of 2 hours and 0.8 pounds per square inch over a period of 15 hours was recorded.

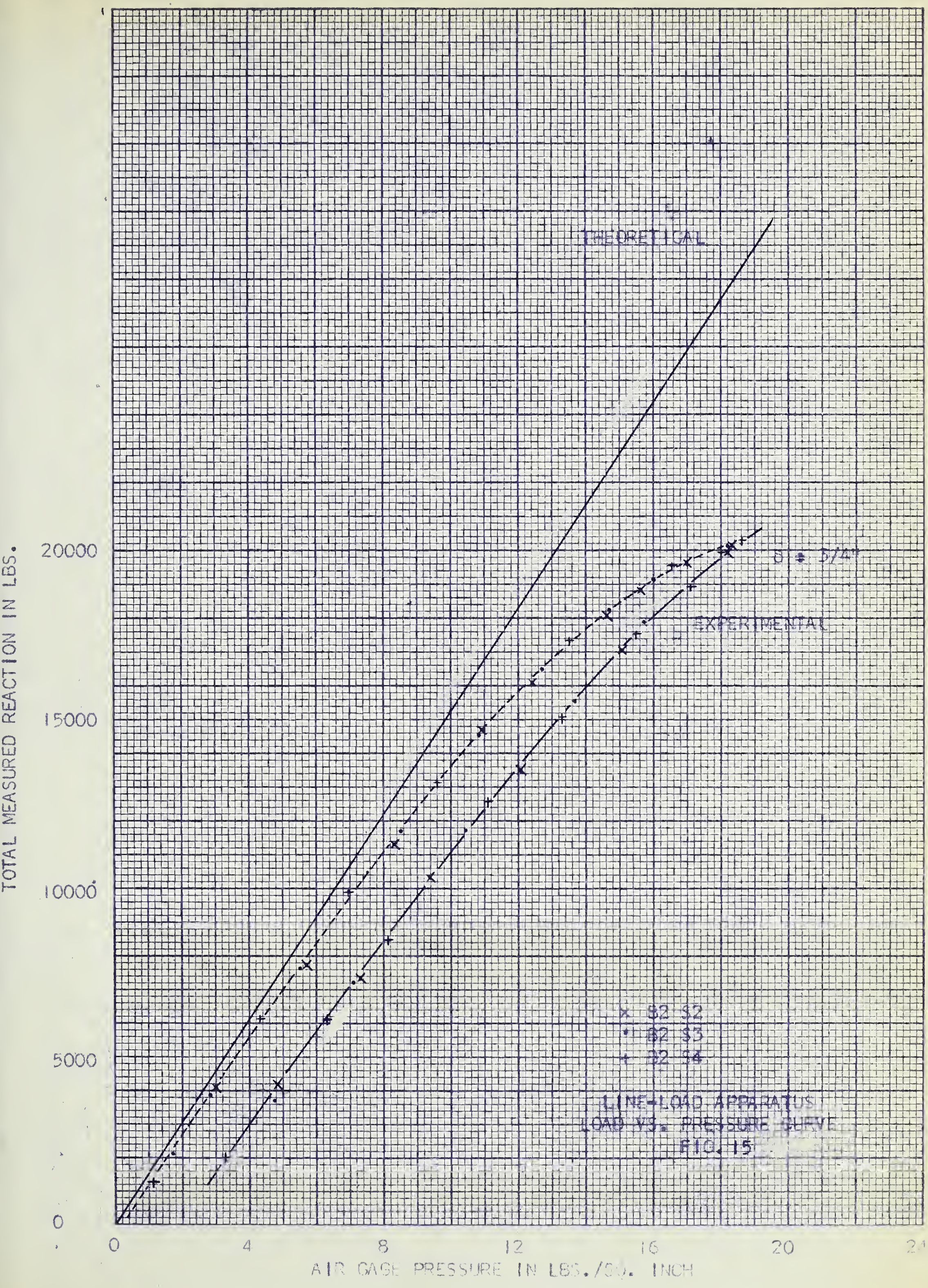
B2 S2 - The maximum load of 20,180 pounds (approximately 150% of design) decreased to 19,950 pounds (1.1% of maximum) over a period of 1 1/2 hours.

B2 S8 - The maximum load of 27,150 pounds (approximately 200% of design) decreased by 1.2% with a corresponding pressure drop of 0.2 pounds per square inch over a period of 1 hour and 40 minutes.

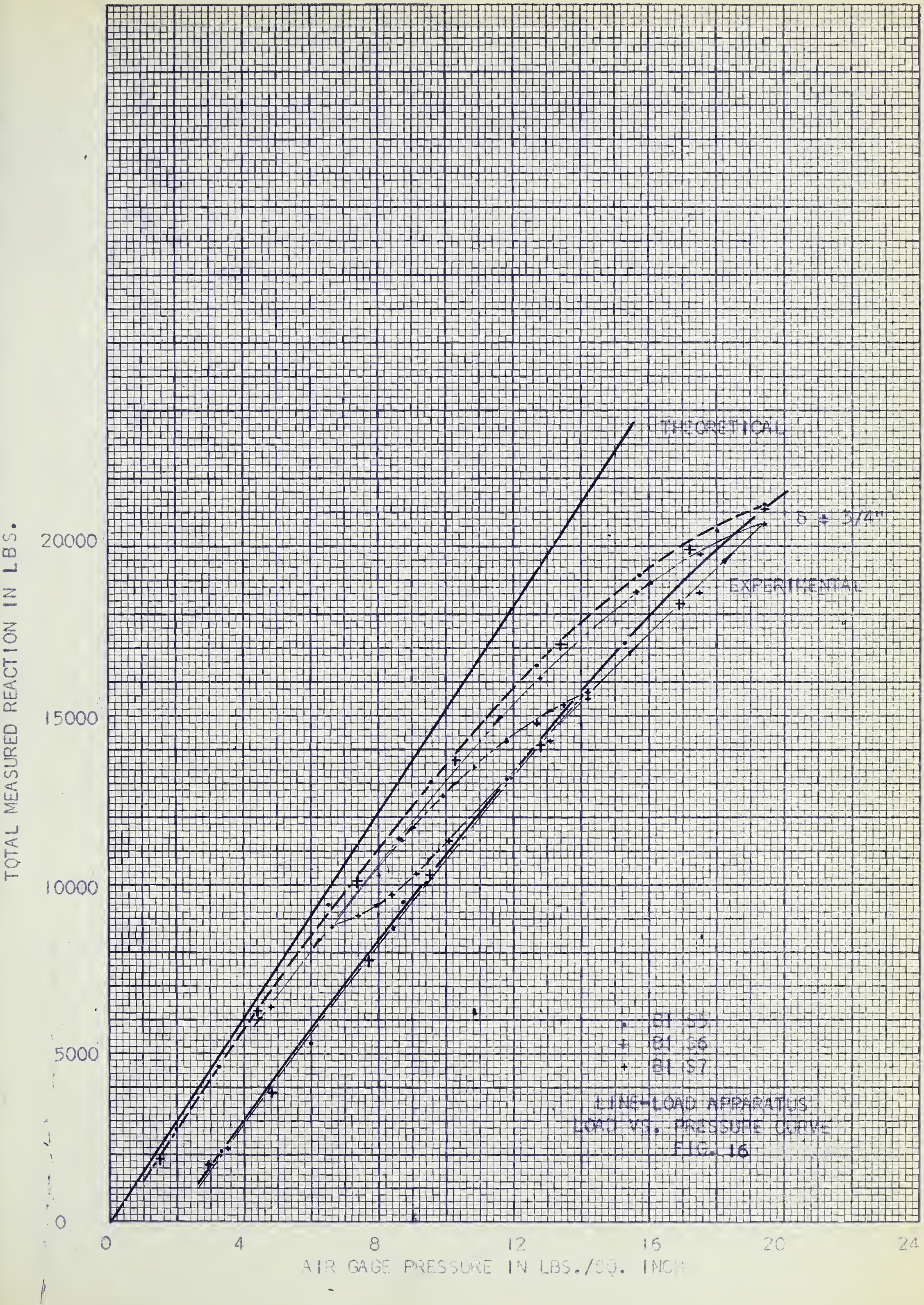
The theoretical curve of load versus pressure is based on the tube chamber 6 3/8" wide and 240" long or 1530 square inches in area and the relationship is expressed as

$$W_T = 1530\ p$$

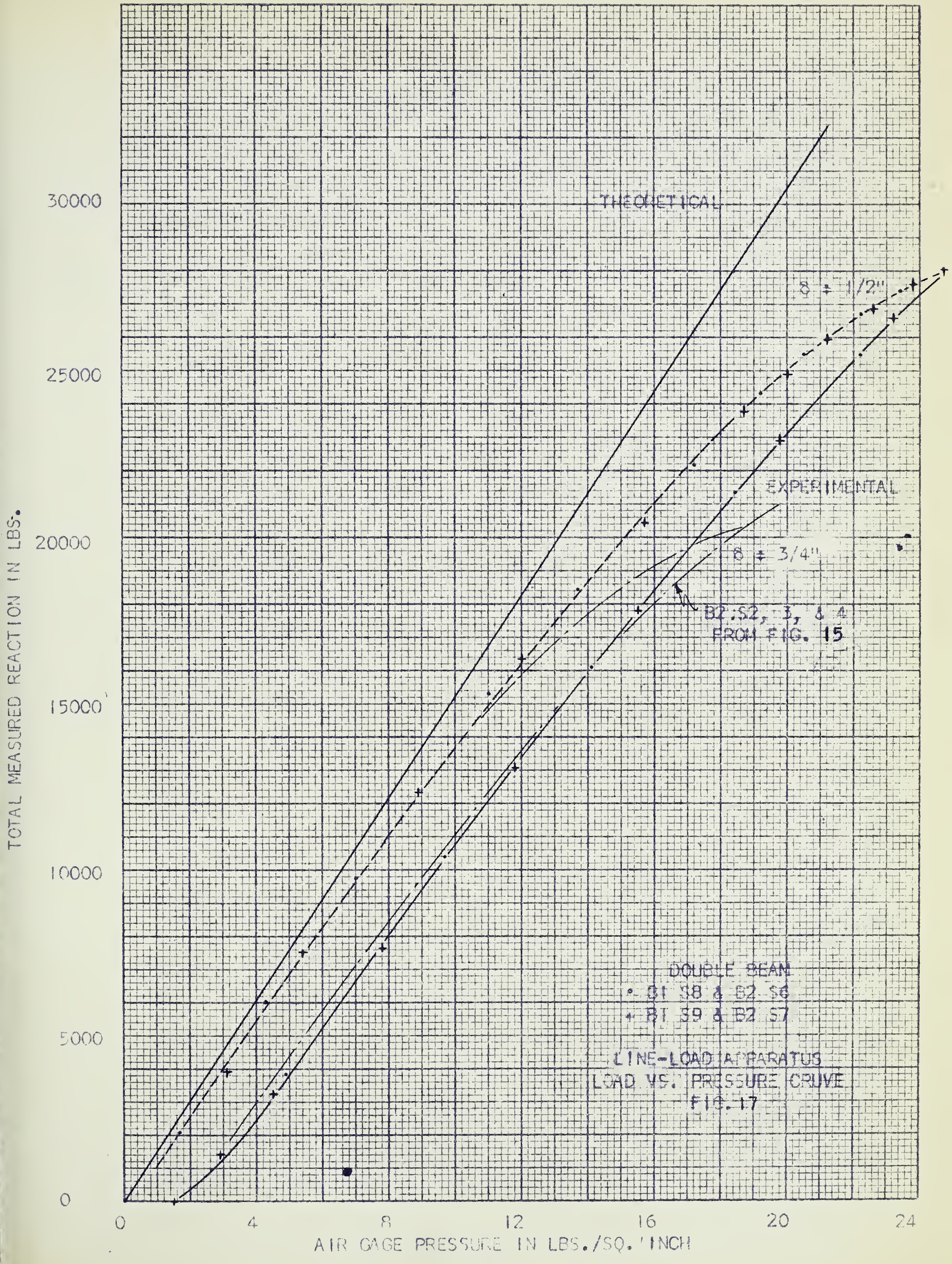
where W_T = total theoretical load capacity of the apparatus in pounds.



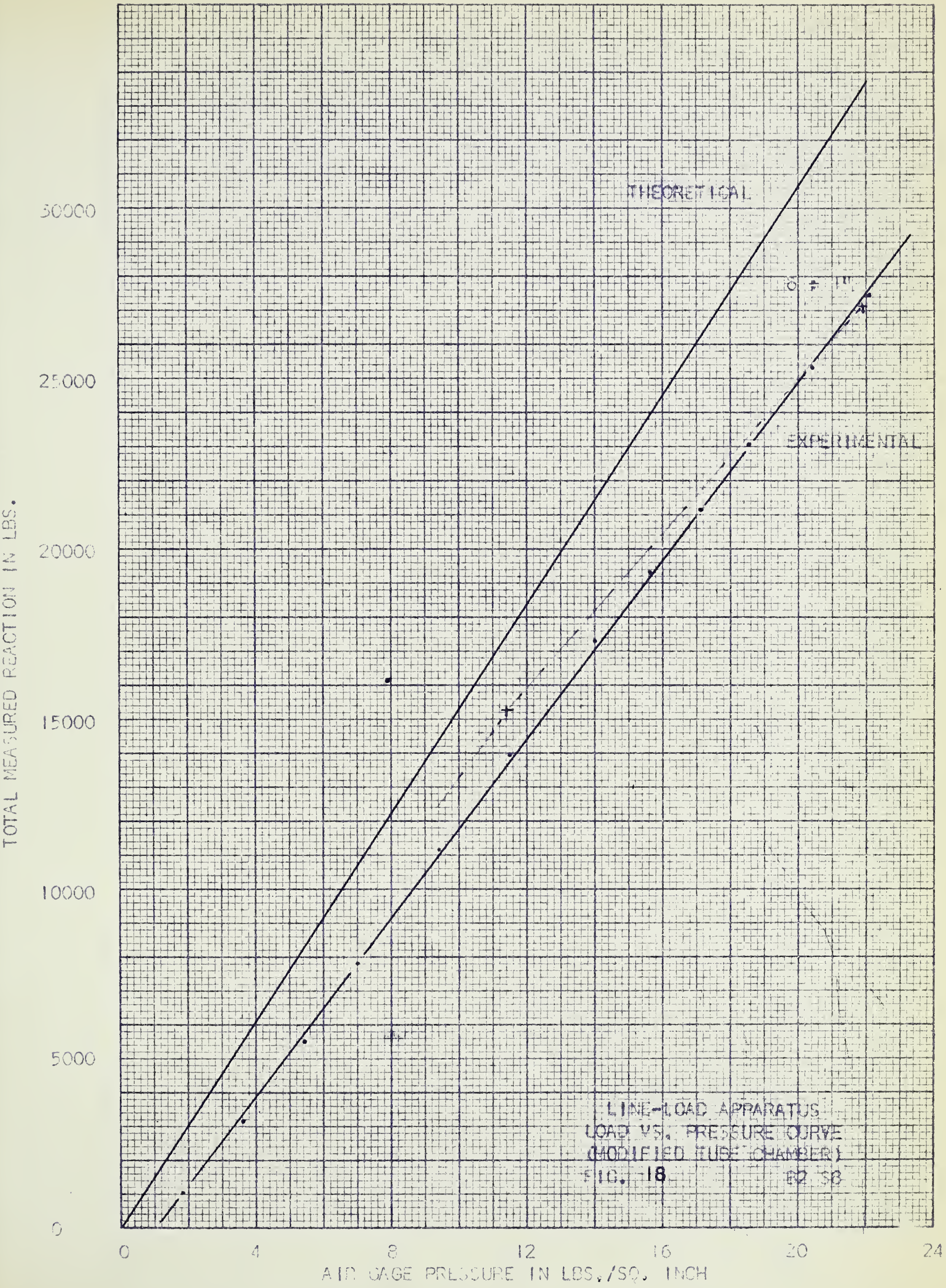
LINE-LOAD APPARATUS
LOAD VS. PRESSURE CURVE
FIG. 15



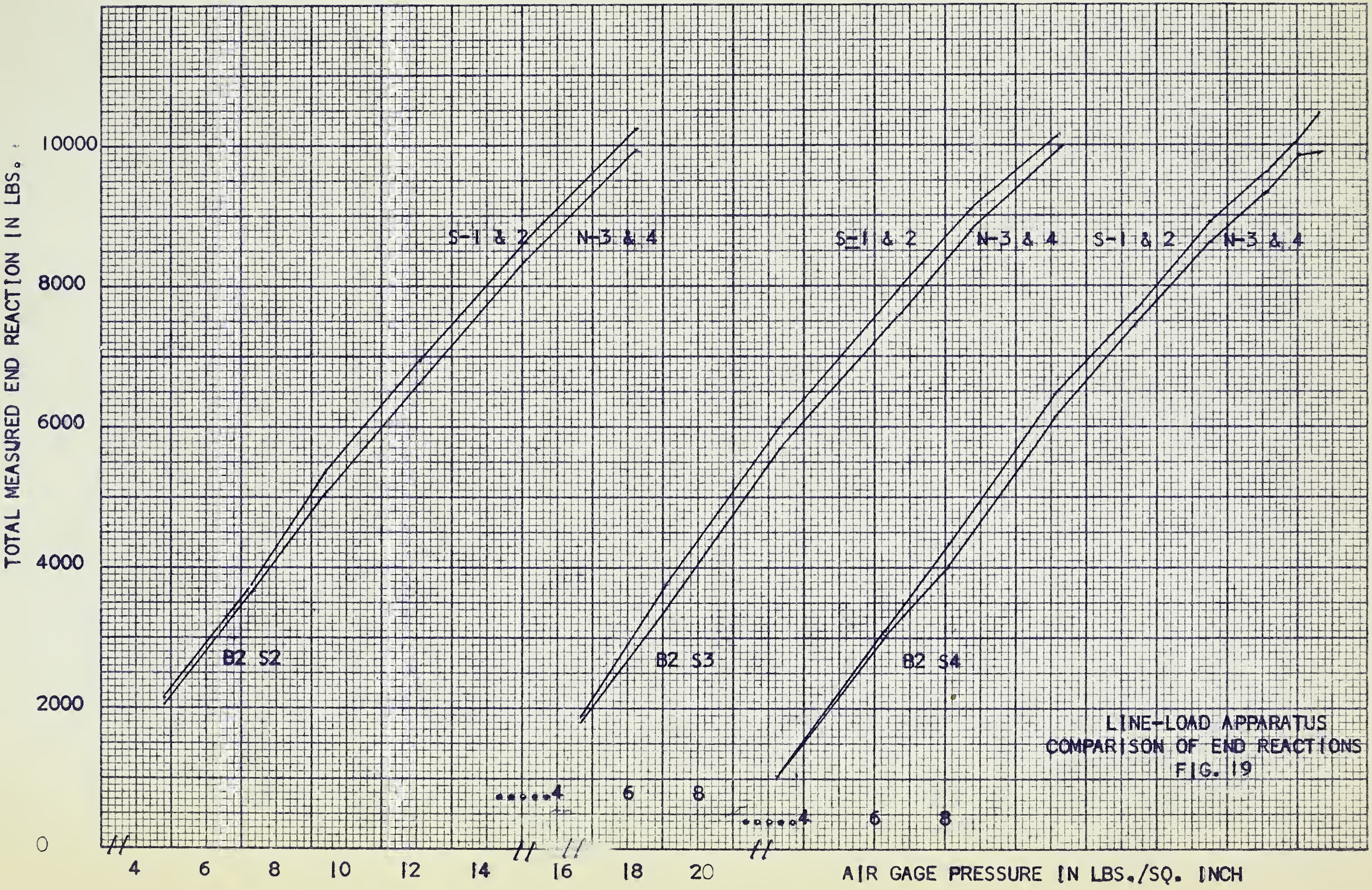
LINE-LOAD APPARATUS
LOAD VS. PRESSURE CURVE
FIG. 16



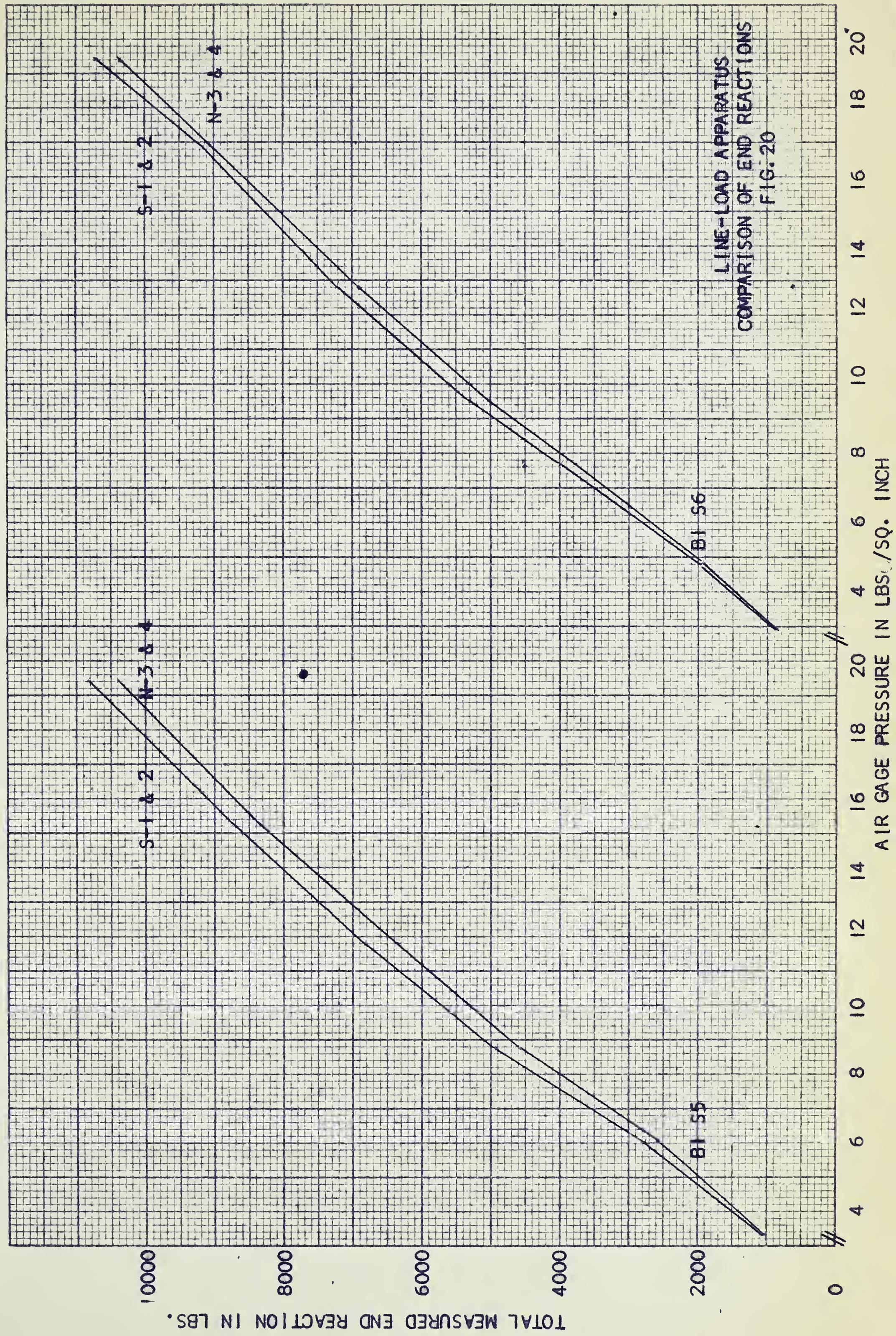
LINE-LOAD APPARATUS
LOAD VS. PRESSURE CRUVE
FIG. 17



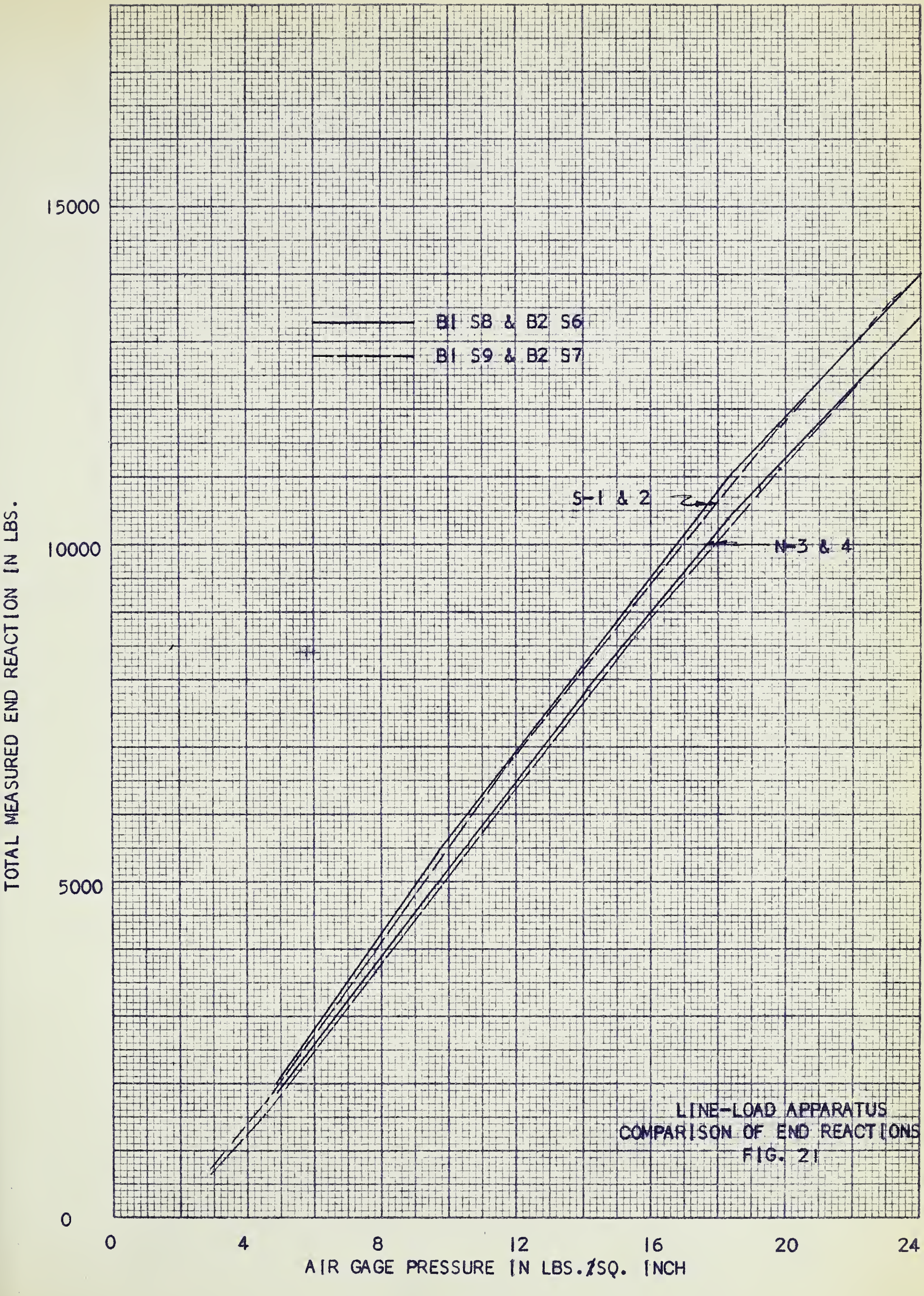
LINE-LOAD APPARATUS
LOAD VS. PRESSURE CURVE
(MODIFIED TUBE CHAMBER)
FIG. 18
62 SB



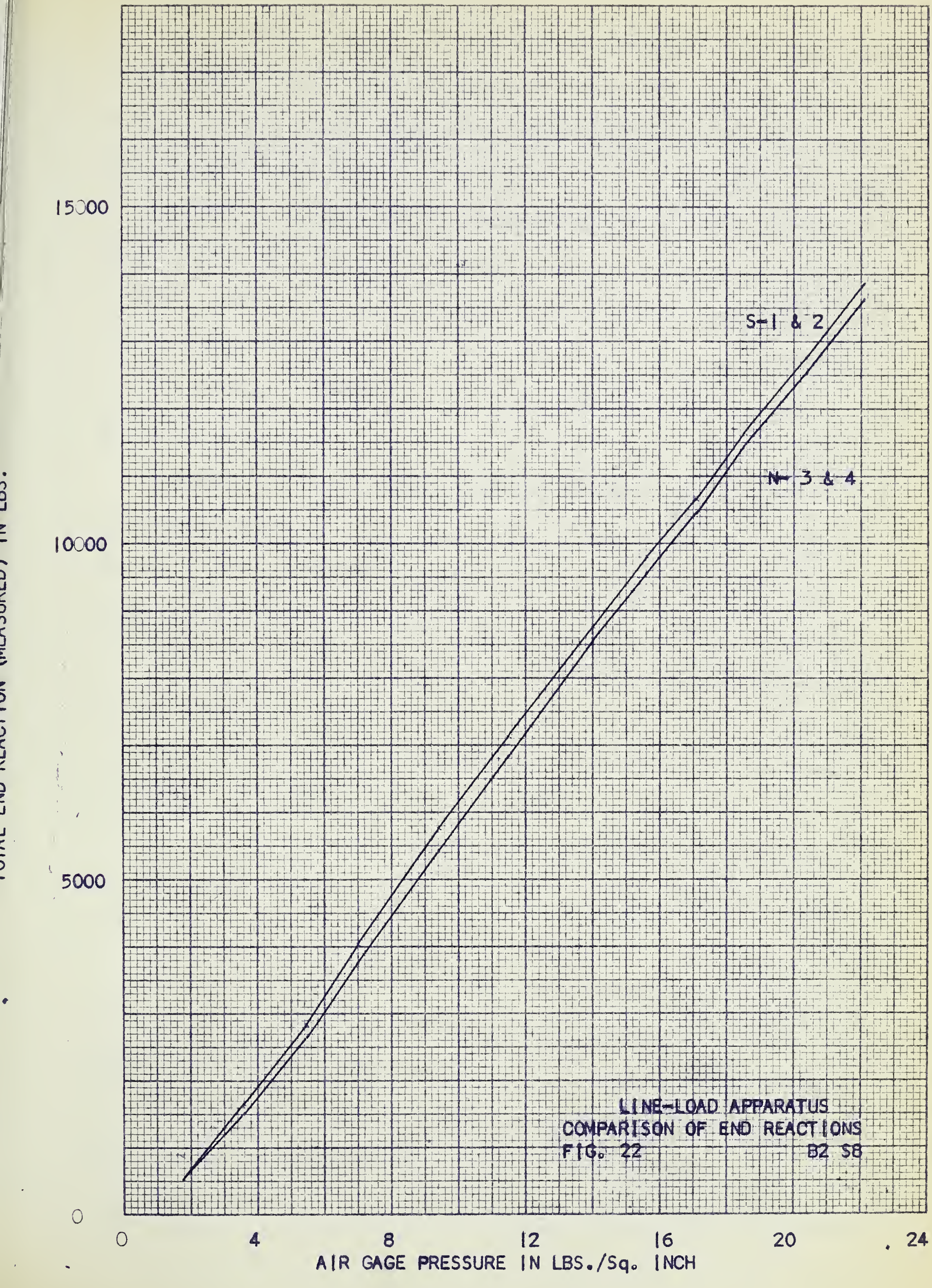
LINE-LOAD APPARATUS
COMPARISON OF END REACTIONS
FIG. 19



LINE-LOAD APPARATUS
COMPARISON OF END REACTIONS
FIG. 20



LINE-LOAD APPARATUS
COMPARISON OF END REACTIONS
FIG. 21



LINE-LOAD APPARATUS
COMPARISON OF END REACTIONS
FIG. 22 B2 S8

VI Discussion of Results

1. Load-Pressure Relationship

The experimental curve of figure 15, the heavier lined curve of figure 16 and the double beam loading curve of figure 17 are very similar with the first two identical except for the small and inexplicable difference at maximum load.

In figures 15 and 16 the loading portion of the load-pressure relationships are, for the most part, flat curves which are almost linear to 14000 pounds (approximately 700 pounds per lineal foot). The unloading portion of the curves are similar but have more curvature and approach the theoretical line almost asymptotically with decreasing load.

Considering the arrangement of the material enclosing and protecting the tube, it can be seen that in the process of loading energy is lost to friction and expanding the tube. Energy is used to deflect the beam; to stretch the rubber tube; to overcome friction between the canvas and the tube, the distribution blocks and the tube, and the friction in moving the blocks. The energy required to deflect the beam is recoverable if the beam behaves elastically in the range of loading. The energy required to stretch the rubber tube is partially recoverable. The other energy requirements are not recoverable and in addition, more energy is lost to moving the blocks downward in the process of unloading.

The deflection of the beam at the center of span is a measure of the cross-sectional area of the tube and the volume of the tube is directly proportional to this deflection when bending is symmetrical about the center of the beam. Various graphs in Part II indicate that the deflection is directly proportional to load. Therefore the volume of the tube is directly proportional to the load. If such is the case,

the ordinate to the load-pressure curve could be changed to represent the volume of the tube. It can therefore be said that a volume-pressure plot would have the same shape as the load-pressure plot. Thus the area under the loading branch of the curve represents the useful work done in loading the beam. The area under the unloading branch of the curve also represents the useful work done under the same pressures when the beam is unloaded. The difference in these two areas represents the energy lost to friction and expansion. The energy lost in moving the blocks up and down is not included in this difference.

The reload curve of cycle BI S7 of figure 16 has the characteristics of a hysteresis loop.

2. Time Effect

A study of the various intervals of loading indicates that 125% of the design load of the beams once applied could be sustained for 40 minutes and longer without any measureable decrease. The dropping of the pressure after such an interval may be attributed to a creep in the tube enclosure and also yielding of the beams. However, there is no evidence that permits separating these two causes. Evidence in presented in Part II to the effect that the beams did acquire a permanent set but this is not necessarily due to what is generally considered as yielding under sustained load.

3. Deflection

Examination of the tube before commencement of the testing program aroused some suspicion as to what its performance would be on expansion and particularly when it reached its maximum unstretched volume. The cross-section of the tube was fabricated as is illustrated in figure 26(a). This cross-section was used for approximately the middle 2/3 of the length and was then gradually tapered to the ends. The tube chamber was fabricated 6 3/8" wide. With this width of tube and the

additional thickness of the enveloping canvas, the tube fitted very tightly in the chamber.

The loading portion of the double beam loading curve of figure 17 illustrates clearly the effect that the deflection of the tube had on the linearity of the load-pressure curve. A plot of midspan beam deflection versus air pressure is shown in figure 23. It is assumed that the tube expands as much at midspan as the beam deflects. This curve exhibits the same properties as the load-pressure curves for the single beam loadings and a reduction of the ordinate scale would make it almost identical. The lower portion of this curve is much straighter than the upper and although the point of rapid change in slope is not well defined it appears to be at a deflection slightly less that the maximum unstretched sidewall height of the tube. Keeping the deflection of the tube to below this limit by doubling the stiffness of the restraint, i. e., by loading 2 beams simultaneously, produced a more linear load-pressure curve and thus a greater uniformly distributed load was obtained.

4. Modifications in Apparatus

The consideration of deflection led to modifying the tube chamber and tube protection to that shown in figure 26(b). The change brought about the load-pressure relationship shown in figure 18. This change illustrates the effect of the absence of the constraining canvas tube protector and also the effects of the reduction in expansion of the tube. Although the arrangement in the tube chamber was not entirely satisfactory, i. e., the lack of an adequate tube protector, the obtaining of a linear load-pressure relationship was the important item insofar as the testing program was concerned.

Referring to figure 18, the intercept of the extended experimental line with the ordinate axis is 1220 pounds and is attributed to the weight of the beam and the reaction mechanism and friction. The slope

of the line is 1308 square inches and the load-pressure relationship may be expressed as

$$W_m = 1308\ p - 1220$$

where W_m = total measured load on the span in pounds. The 1220 pounds is an experimental constant that consists of two components. Since W_m is the load as measured by the reaction rods, it does not include the weight of the beam, the distribution blocks or the reaction rods which in total amount to 600 pounds and are lifted by the force of the tube. The difference between 1220 and 600 pounds, 620 pounds, may be attributed to the friction in the tube chamber and possibly some stretching in the tube. If it is assumed that this friction load is distributed over the length of the apparatus it amounts to 3.1 pounds per lineal foot, a figure which appears reasonable.

The above equation can also be expressed in the form

$$W_m = 0.855\ Ap - 1220$$

and the total load delivered by the tube is

$$W_e = 0.855\ Ap = W_m + 1220$$

The theoretical capacity of the apparatus is

$$W_t = Ap$$

and therefore the efficiency is

$$\frac{W_e}{W_t} \times 100 = 85.5\%$$

Furthermore, the load intensity can be expressed as

$$w_e = 0.855\ \frac{Ap}{20} = 0.0428\ Ap$$

and

$$w_m = 0.855\ \frac{Ap}{L} - \frac{1220}{L} = 0.0428\ Ap - 61$$

where w_m = measured intensity of load in pounds per lineal foot and w_e is as previously defined.

The maximum uniformly distributed load that was obtained with the modifications shown in figure 26(b) and as described above was approx-

[illegible]

$$[illegible]$$

[illegible]

[illegible]

$$[illegible]$$

[illegible]

$$[illegible]$$

[illegible]

$$[illegible]$$

[illegible]

$$[illegible]$$

[illegible]

$$[illegible]$$

[illegible]

$$[illegible]$$

[illegible]

[illegible]

imately 1375 pounds per lineal foot.

5. End Reactions

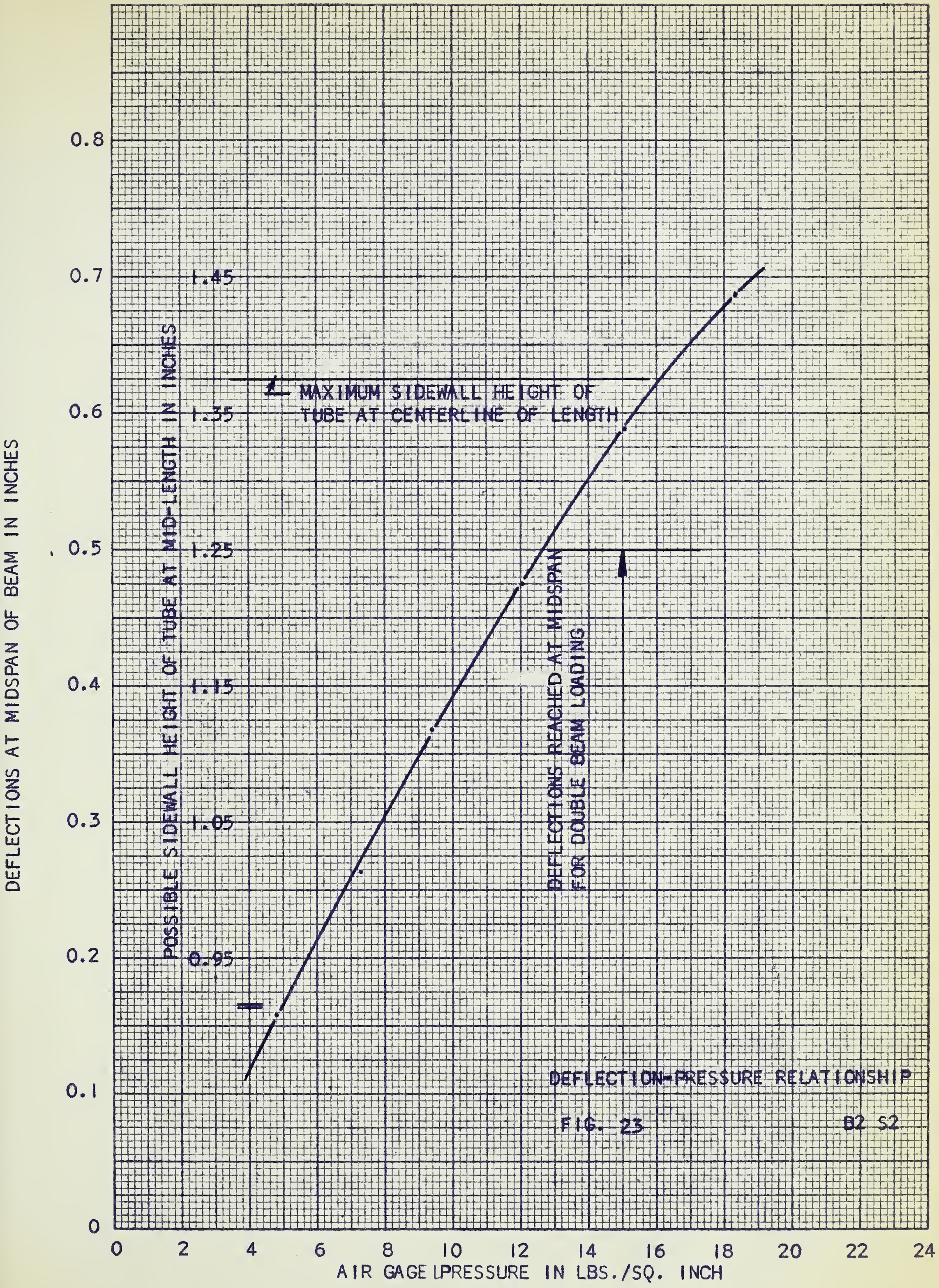
Figures 19 to 22 are plots of the end reactions for each load - pressure curve presented. These indicate that the reaction at the north or valve end of the apparatus was consistently lower than that at the south end. This difference for most of the loading cycles appears to be constant and about 300 pounds for all reactions in excess of 5000 pounds. A single plot of all the calibration curves for the double-gaged rods which is shown on figure 24 demonstrates a similar consistency, i. e., for loads in excess of 2500 pounds on each rod the sum of the calibration curves for rods 3 and 4 is less than the sum of curves 1 and 2 and the difference is approximately equal to the difference in the observed sums of the end reactions. This discrepancy is small and amounts to about 2% of the design load of the beams.

6. Predictability of Load

The air gage is not essential in the apparatus for measuring the load but merely acts as a check on the distribution of loading. The load is measured by the strains in the reaction rods and the maximum possible error based on the discrepancy of readings noted under 'Instrumentation', page 15, is 150 pounds. However, the plots of the end reactions indicate that this error is about 300 pounds with a max-

imum of 600 pounds in the case of the double beam loading. As mentioned previously, this amounts to about 2% of the design load of the beams.

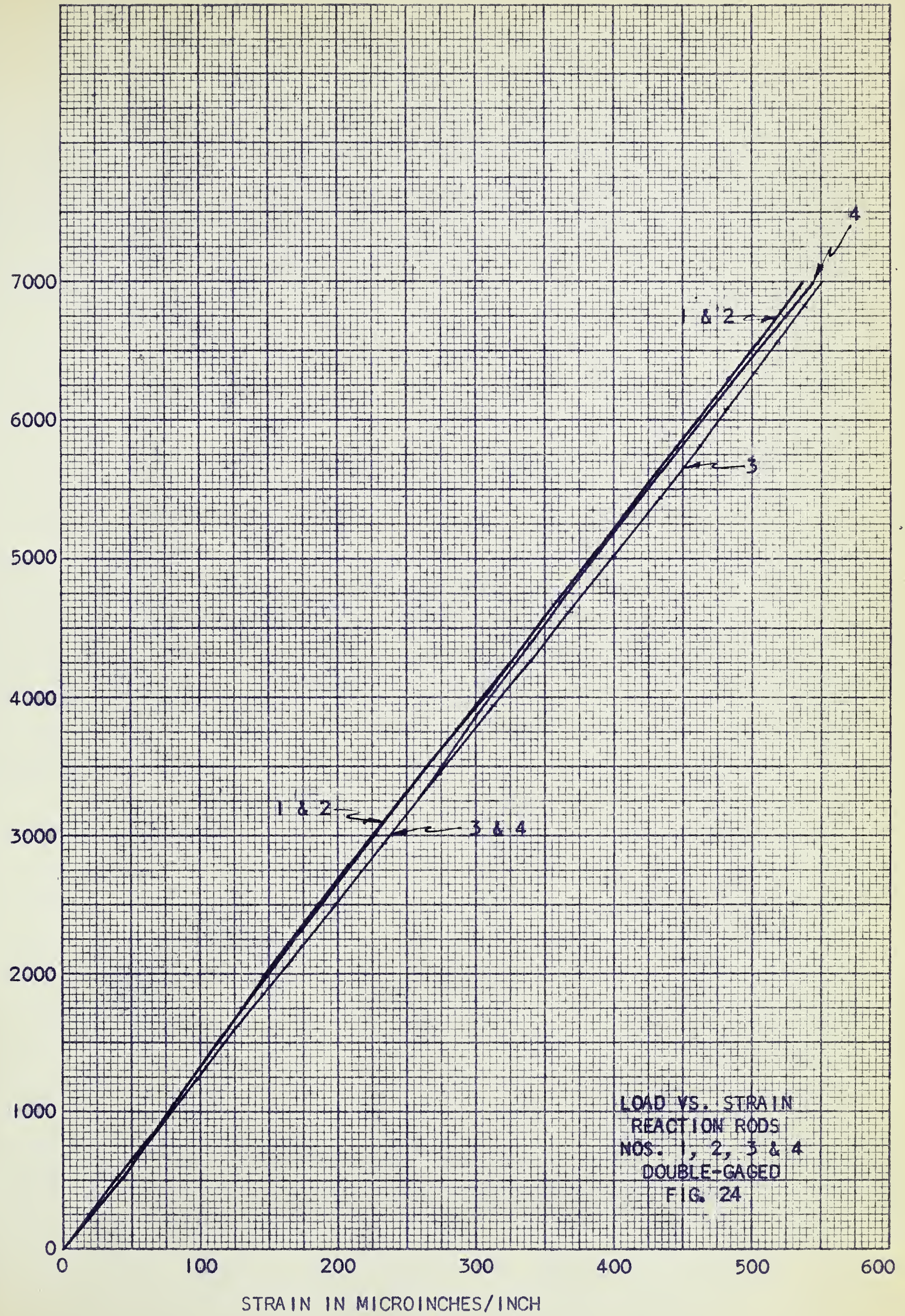
The load is assumed to be uniformly distributed only in as much as the load-pressure relationship is linear. Since the pressure is constant over the length of the tube the linearity implies that the load is added in equal amounts over the whole span. One might expect that the load in the immediate vicinity of the reactions would not be the same as for the remainder of the span. In order to obtain absolute certainty of distribution of load it would be necessary to take samplings of load along the length of the apparatus. Figure 25 illustrates for a particular condition, what variation in distribution could be tolerated without appreciably affecting the analysis in Part II. The plot of figure 25 is based on theoretical considerations only and indicates that for a uniform variation of intensity of loading of 20% over half the span, the strain in the extreme fibre at mid-span varies only by 3.5%. The calculations are presented in this graphical form in view of further considerations which are given in Part II.



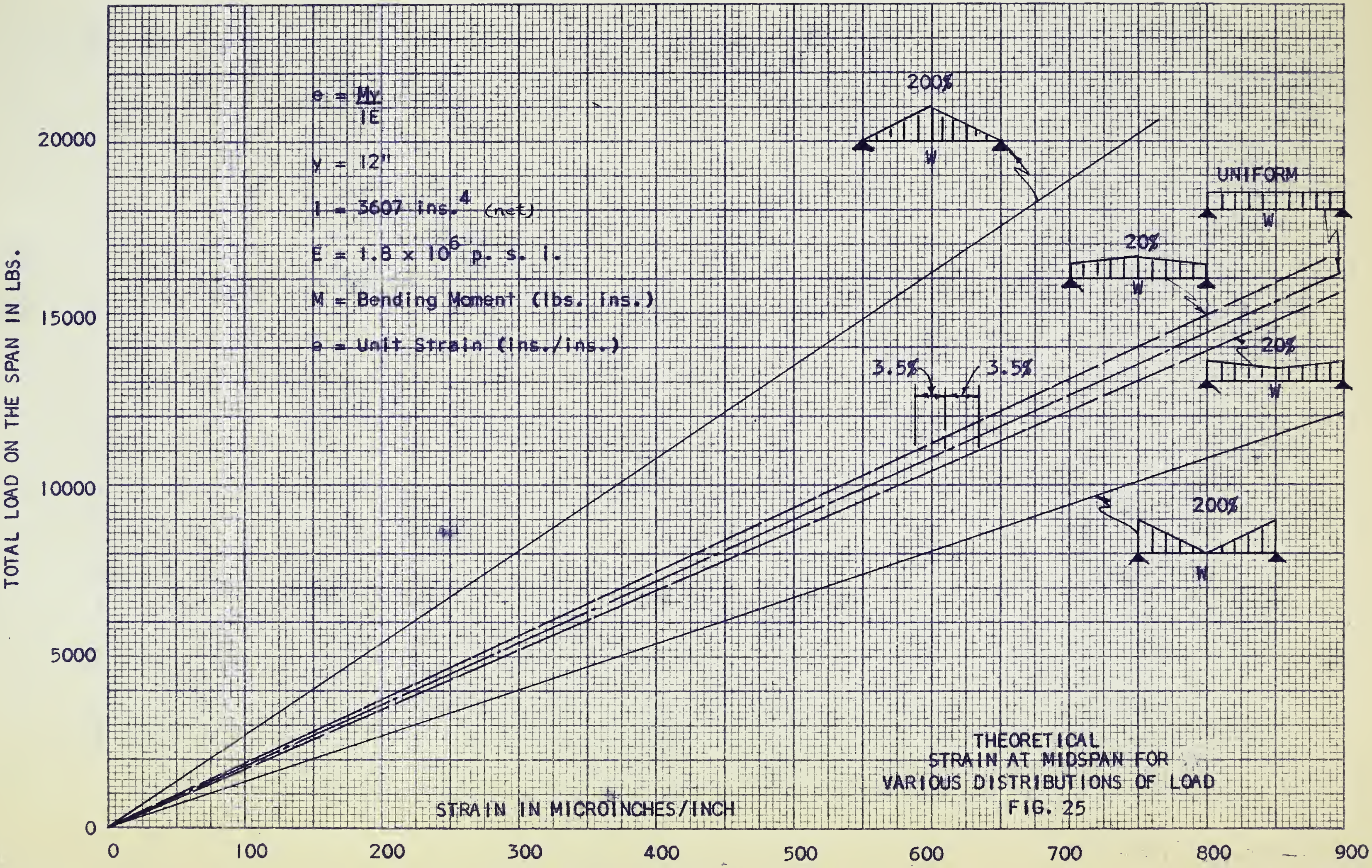
DEFLECTION-PRESSURE RELATIONSHIP

FIG. 23

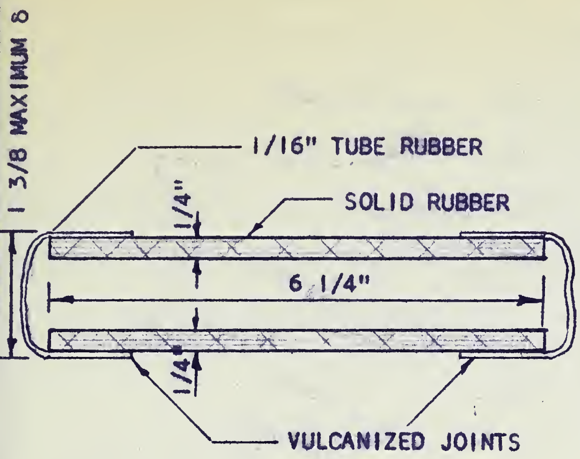
B2 S2



LOAD VS. STRAIN
REACTION RODS
NOS. 1, 2, 3 & 4
DOUBLE-GAGED
FIG. 24



THEORETICAL
STRAIN AT MIDSPAN FOR
VARIOUS DISTRIBUTIONS OF LOAD
FIG. 25

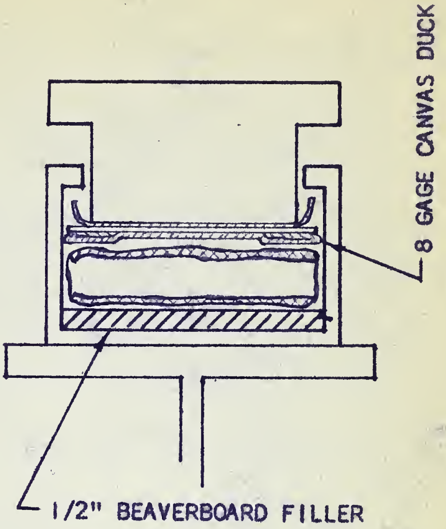


SECTION THROUGH PNEUMATIC TUBE

AT MID-LENGTH

FIGURE 26a

1/2 SIZE

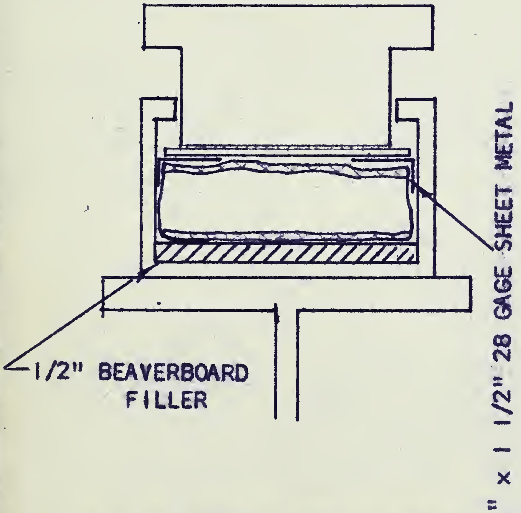


SECTION THROUGH TUBE CHAMBER

FIGURE 26b

3" = 1'-0"

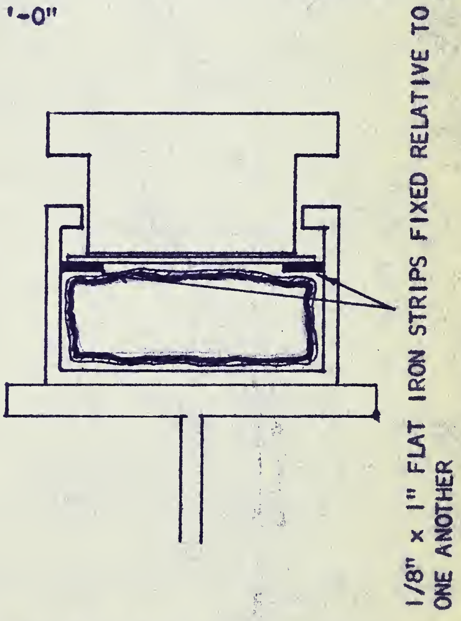
3" = 1'-0"



SECTION THROUGH TUBE CHAMBER

FIGURE 26 c

3" = 1'-0"



SECTION THROUGH TUBE CHAMBER

FIGURE 26d

VII Conclusions

1. The apparatus was tested to a maximum total load of 27,150 pounds (27% of its designed range). A uniformly distributed reactive-type load of 700 pounds per lineal foot over a 20 foot span was obtained using the original design of the pneumatic tube chamber. By modifying this design this load was increased to 1375 pounds per lineal foot for the same span. Further modification in the tube chamber would be necessary to protect the tube.

2. The distribution of load was a function of the expansion of the tube and was uniform when the volume of the tube was less than its maximum unstretched volume.

3. The apparatus maintained within approximately 1%, a load equivalent to 150% of the design load of the beams for atleast an hour.

4. The maximum total loads on the span were measured with an error in the order of 2%.

VIII Suggested Improvements in the Apparatus

Two major difficulties were encountered in the operation of the apparatus. These were a result of the inadequacy of the tube insofar as its expansion characteristics and the inadequacy of the tube protection. The following suggestions are offered for overcoming these difficulties.

a) A tube of constant cross-section may be used. This cross-section should be large enough so that no stretching of the tube will occur when it is expanded to its maximum rectangular form in the tube chamber (6 3/8" x 3"). This would insure uniformity of load on a span of any length up to 20 feet and will permit cantilever testing.

b) The protective covering may be incorporated in the tube wall and the tube may be made capable of sustaining its design pressure without exterior support. The object is to minimize friction and still protect the tube from being pinched. The protective metal strips shown in figure 26(d) can be fitted in place with a total clearance of less than 1/8". It is necessary that the tube be flexible enough to fill the chamber yet stiff enough so as not to be pinched. A length of 6" fire hose would have the ideal dimensions and protective covering although it might prove to be too stiff and not be leakproof. Making the tube capable of sustaining its design pressure without exterior support would also facilitate destructive testing. However, for this purpose, liquid pressures would have advantages.

PART II

I Introduction

The scarcity of large timber sections used for structural frame elements and the inherent defects in the wood which are usually more pronounced in large sections have led to the development and use of built-up plywood beams. These beams are made of a combination of solid timber and plywood where the plywood is used in the web and the solid timber inthe flanges. In common use are I and box beam sections.

Among the advantages of built-up plywood beams are the following:

A) By concentrating the solid timber in the flanges of the beam the sectional efficiency of the beam is increased. This also makes it possible to use smaller pieces of solid wood which are more available in better grades.

B) The cross-laminations of the plywood which is used in the web provide equal resistance to both vertical and horizontal shearing stresses which is an advantage over solid wood where the ratio of shearing resistances parallel and perpindicular to the grain is low.

C) The plywood provides further advantages in that shrinkage due to loss of moisture is reduced and splitting in any direction becomes next to impossible with a consequent improvement in nailing properties.

D) The dead weight of the beam is reduced.

Beams have been assembled by pressure-gluing, nailing and gluing and also by the use of ring connectors (1). A variety of glues are available for use in different circumstances. Pressures can be obtained by using clamps, presses or nails.

Although plywood was in use prior to World War II, the war provided the greatest impetus for research into the mechanical and physical properties of the material. The greatest contributor to this field of knowledge is the United States Department of Argrculture Forest Products Laboratory at Madison, Wisconsin.

II Scope

The object of this study was to obtain experimental data on the behaviour of built-up plywood box beams under the action of uniform loading.

Two beams were fabricated and loaded to 150% of their design load in a line load apparatus.

Strains were observed over the depth of the beams at midspan, in the vicinity of the web splice and at a point where shrinkage cracks appeared. A comparison was made between the strains recorded with SR-4 electrical gages and 0.0001" mechanical dials placed on 8" gage lengths. Deflections of the beams were measured at midspan.

III Design and Fabrication of Beams

Two identical, 20 foot span, 24" deep, built-up plywood box beams were designed to carry a uniformly distributed superimposed load of 675 pounds per lineal foot. The construction details are shown in figure 27. These beams had box cross-sections 5 1/2" x 24" with 3 webs in the outer 3 feet (section1) and 2 webs in the central 12 foot portions (section 2) of the spans. The webs were made of standard 8 foot plywood panels spliced with plywood plates. The flanges, except for web fillers in the central portions, were continuous over the spans. Web stiffeners were provided at the ends, at the changes in cross-section and in the central portions of the beams. The beams were assembled by gluing.

The following materials were used:

Webs: 5/8" Douglas-fir exterior plywood, solid one side and marked PMBC SL EXTERIOR. The surface moisture content was an average of 2.7%. Splice plates were of 1/4", 3 ply, Douglas-fir shop stock.

Flanges: Continuous, 2" x 4" nominal, 20'-0" long, S4S, clear Douglas-fir (Mountain). The average surface moisture content was 15%. Similar material was used for the flange filler.

Stiffeners: Douglas-fir shop stock.

Adhesive: Casein, Monsanta Adhesive No. 1911, warmed and applied at room temperature of 68°F. The mix used was 1 pound of glue powder to 1 1/2 pounds of water.

The beams were designed in accordance with the recommendations contained in the Douglas Fir Plywood Technical Handbook published by the Plywood Manufacturers Association of British Columbia. The moduli of elasticity for the plywood and solid fir were assumed to be 1.8×10^6 and 1.6×10^6 pounds per square inch respectively. The calculated maximum stresses at design load (690 pounds per lineal foot) were:

Extreme fibre in bending at midspan- 1680 pounds per square inch.

Horizontal shear in the web in section 2 at the juncture

with section 3 - 197 pounds per square inch.

Rolling shear in the web in section 2 at the juncture of section 3 - 26.3 pounds per square inch.

Only the stress in the extreme fibre in bending exceeded the permissible stress. (The permissible bending stress recommended by the C. S. A. Specifications for Structural Timber (043-1953) for select structural grade Douglas-fir, Mountain wood for continuous loading is 1,400 pounds per square inch. The recommended modulus of elasticity is 1.4×10^6 pounds per square inch. The permissible stress for the same material in glued-laminated timber construction is 2370 pounds per square inch (National Building Code, 1953)). The depth of the beams was limited by the size of the apparatus (length of reaction rods only) and since it would have been necessary for the flange material to be slightly larger than available standard sizes, this increase of bending stress over the allowable was permitted. Furthermore, loads were carried to 150% of design only and this excessive stress was not detrimental to the object of the tests, that of observing the wood strains within this range.

The net moments of inertia (based on plywood fibres parallel to the span and solid flange portions of the beam) were 3466 and 3607 inches^4 for sections 1 and 2 respectively. The gross moments of inertia (based on the wood section irrexpective of the direction of plywood fibres) for these two sections were 4626 and 4380 inches^4 respectively. It is suggested in the Douglas Fir Plywood Handbook that an 'effective' gross moment of inertia may be computed by assuming that the modulus of elasticity for Douglas-fir perpendicular to the grain is 1/20th of that parallel to the grain. The 'effective' gross moment of inertia of section 2 computed in this manner was 3646 inches^4 or 1.3% greater than the net moment of inertia. This difference was considered negligible and in later computations, net moments of inertia

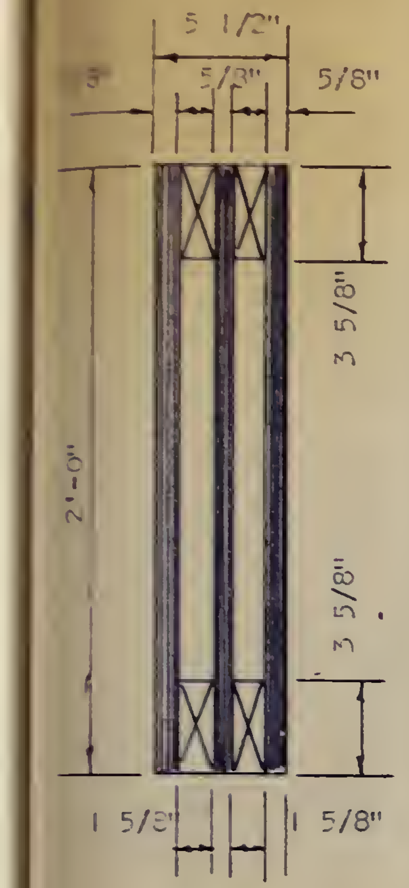
were used. The ratio of the net moments of inertia about the horizontal axis to that about the vertical axis at midspan was 32:1. It was felt that the method of loading would provide lateral support to the compression flange and no further precaution was made against lateral buckling of the compression flange. The calculated midspan deflection at design load was 0.440 inches due to bending and 0.103 inches due to shear or a total of 0.543 inches. The deflection due to bending was computed using 1.6×10^6 pounds per square inch as the modulus of elasticity and the average net moment of inertia, 3536 inches^4, of sections 1 and 2. The deflection due to shear was computed using 117,000 pounds per square inch as the modulus of rigidity and the average gross moment of inertia, 4503 inches^4, of sections 1 and 2.

The plywood beams were fabricated locally. Room temberature at the time of fabrication was controlled at 68°F. and the relative humidity was 35%. The glue was spread with a roller on both gluing faces and these were fixed together with a few nails. Pressure was applied to the glue areas on the flanges only and this was accomplished with U-clamps spaced at approximately 16 inch centers using a calibrated torgue wrench to produce a pressure of 100 pounds per square inch over the area being glued. The beams remained under pressure in the shop for a minimum of one day.

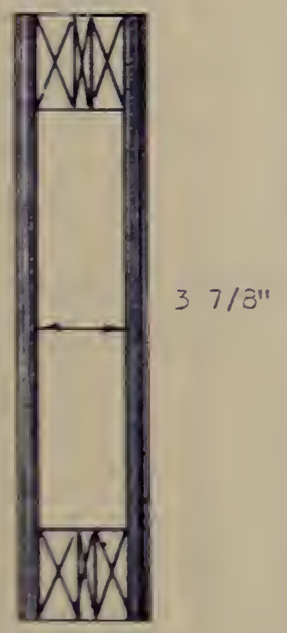
The beams were stored for aperiod of 3 1/2 months (February to May) in the Structural Laboratory. This period of storage was not anticipated and consequently temperatures or humidities during that time were not recorded. The temperature in the laboratory was under thermostatic control at 70°F. with the relative humidity from 25 to 30% (estimated). In spite of the lack of recorded data in this respect it can be said with certainty that the storage conditions were more moderate than may be expected in normal service. Photographs of figures 31 and 33 were taken prior to loading to illustrate the effects

of the differential shrinkage that had taken place during storage.

A minor change was introduced during fabrication. The end stiffeners were changed from 2" x 4" to 2" x 6" and the intermediate stiffeners from 1" x 4" to 2" x 4". Larger material was used in the end stiffeners because the flange members were 20'-0" long (stock size) and the beams had to be made a few inches longer for adequate end bearing in the apparatus (figure 27 is the construction drawing of the beams as fabricated). The fabricator changed the intermediate stiffeners to 2" x 4".

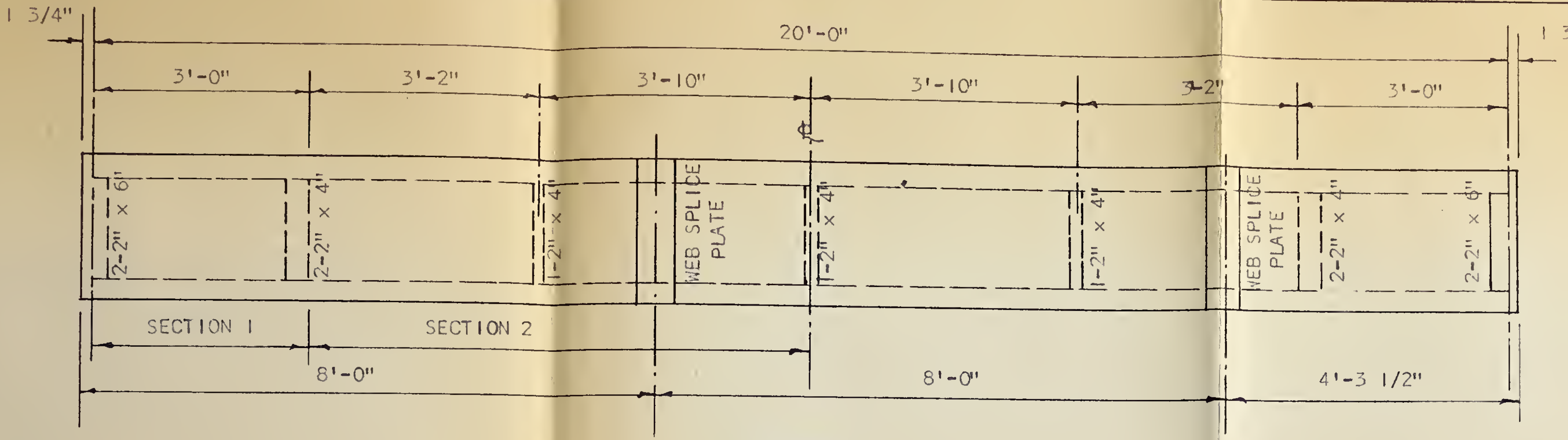


SECTION 1



SECTION 2

SCALE : 1 1/2" = 1'-0"



ELEVATION

SCALE: 1/4" = 1'-0"

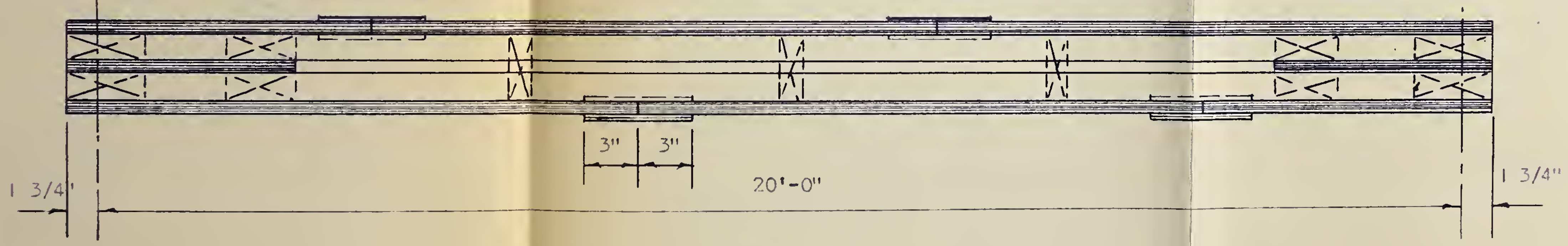
FLANGE MATERIAL-2" × 4" DOUGLAS FIR (INLAND), GRADE A CLEAR, CONTINUOUS FOR 20'-0" (MOISTURE CONTENT 15%)

WEB MATERIAL-5/8" PMBC EXTERIOR DOUGLAS FIR PLYWOOD (MOISTURE CONTENT 2.7%), PLYWOOD S1S

WEB SPLICE PLATES-1/4" PMBC EXTERIOR DOUGLAS FIR PLYWOOD; INSIDE PLATES NAILED AND GLUED.

GLUE-MONSANTA ADHESIVE CASEIN #1911, WARMED AND APPLIED AT ROOM TEMPERATURE OF 68°F; MIX: 1# GLUE POWDER TO 1 1/2# WATER

GLUING PRESSURE 100 P.S.I. AND RELATIVE HUMIDITY OF SHOP 35%



PLAN

FIG. 27
20 FT. PLYWOOD BOX-BEAM
DESIGN LOAD 675#/LINEAL FOOT

IV Experimental Procedure

1. Loading

The Line Load apparatus as described in Part I was used for loading the beams.

2. Instrumentation

Wood strains were measured with SR-4, Type A-3, Baldwin - Southwark electric gages. These were applied according to manufacturers' specifications using C. I. L. Household cement. The gages were checked for electrical non-conductivity between their leads and the material on which they were placed. The gages were positioned as shown in figures 29 and 30. (The beams are shown with their surfaces developed.) Protective coverings were provided for the gages at midspan on the load side of the beams. These consisted of small pads approximately 1/4" x 3/8" x 3" fixed to the beam face (flange) between the gages such that the gages and connecting wires were completely free of the distribution blocks of the apparatus. The recording instrument was a Baldwin Type L Indicator.

Wood strains were also measured with the following 0.0001" mechanical dials:

A - AMES, No. 10 with a 0.3000" range.
B - CENCO with a 0.3000" range.
C - STARRET, No. 25TI, D5D, with a 0.0250" range.

These dials were positioned on 8.00" gage lengths using 1/8" x 1/2" flat iron strips. The arrangement of 2 of these dials is shown in figure 28. Their positions on the beams are shown in figures 29 and 30.

Surface moisture contents were measured using an electric meter supplied by the fabricator of the beams. About 6 readings were taken for each determination.

Deflections at midspan of the means were measured with 0.001" AMES dials.

3. Testing Procedure

All observations on the behaviour of the plywood beams were made simultaneously with the testing of the Line Load apparatus. The beams were placed singly on the load distribution blocks of the apparatus and the end bearing plates were adjusted to give full bearing across the end faces of the beams. Generally, the beams were loaded and unloaded in increments of 1/4 design load (13,800 pounds total). Both beams were also inverted and loaded. After the application of each load increment sufficient time was allowed to elapse to give steady readings on the strain indicator. In longer intervals between loadings strain readings were taken immediately after the load had been applied and a number of readings were checked immediately before applying the next increment of load. The performance of strain dials A and B was very sluggish at times necessitating a few taps of a pencil. These two dials were discarded after the first few tests.

The following tabultation indicates the various tests conducted. Each test is denoted symbolically, for example, B2 S2, refers to the second cycle of loading and unloading beam No. 2.

B1 S1* - Loads were applied in 25 minute and longer intervals to a maximum of 150% of design load.

B1 S2** - Loads were applied in intervals up to 40 minutes to a maximum of 150% of design load.

B1 S3 - The beam was loaded to 150% of design and the load was left on for 15 hours. Strain indicator readings displayed some inconsistancy making it impossible to record changes in strain at maximum load.

B2 S1 - Loads were applied in 20 minute intervals to a maximum of 150% of design load. Strain readings were very irratic. While loading and at approximately 75% of design load, the crack shown in figure 31 extended itself over the full length of the panel (8'). In spite of the difficulty with the main switch on the strain indicator, readings for each increment of loading were taken and repetedly checked with the result that although the absolute differences in strains were not known, each sent of readings was consistent.

B2 S2 - Loads were applied in intervals of 15 minutes to 150% of design load.

B2 S5 - Loads were applied to the beam in 15 minute intervals to a maximum of 150% of the design load.

* The 1 1/2" diameter reaction rods were used in the apparatus. The experimental plot was made using loads as determined by air gage pressure from the load-pressure graph of figure 16, page 29, B1 S5 & B1 S6.

** The 3/4" diameter single-gaged reaction rods were used in the apparatus.

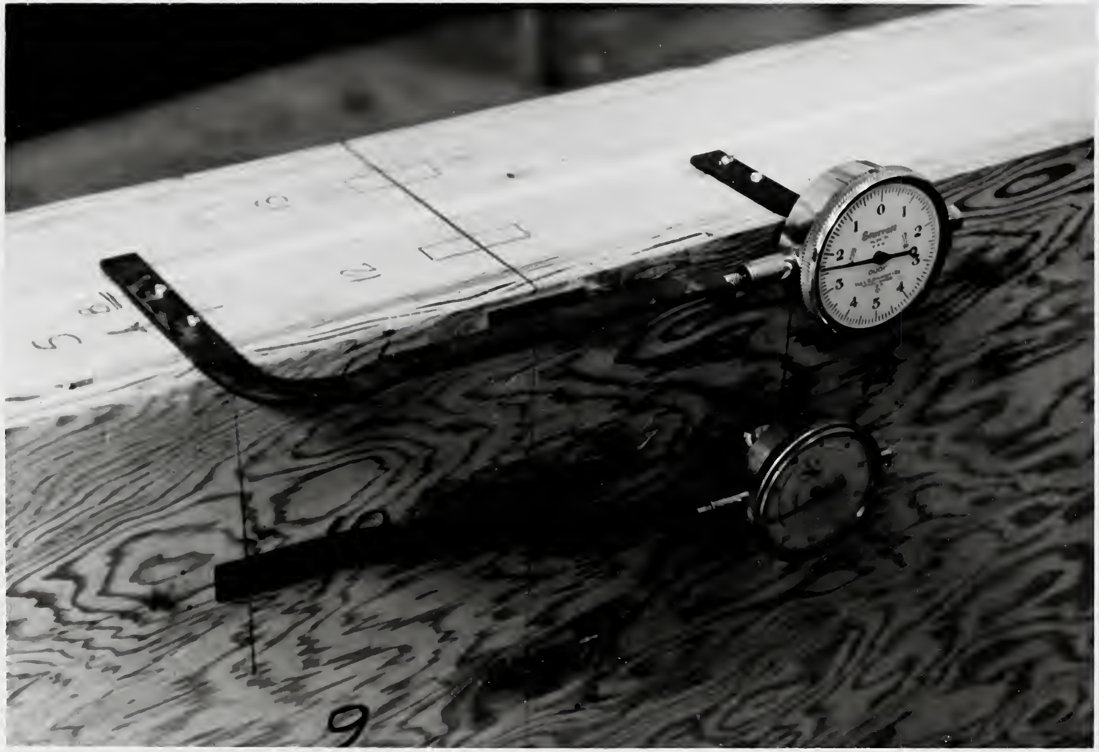
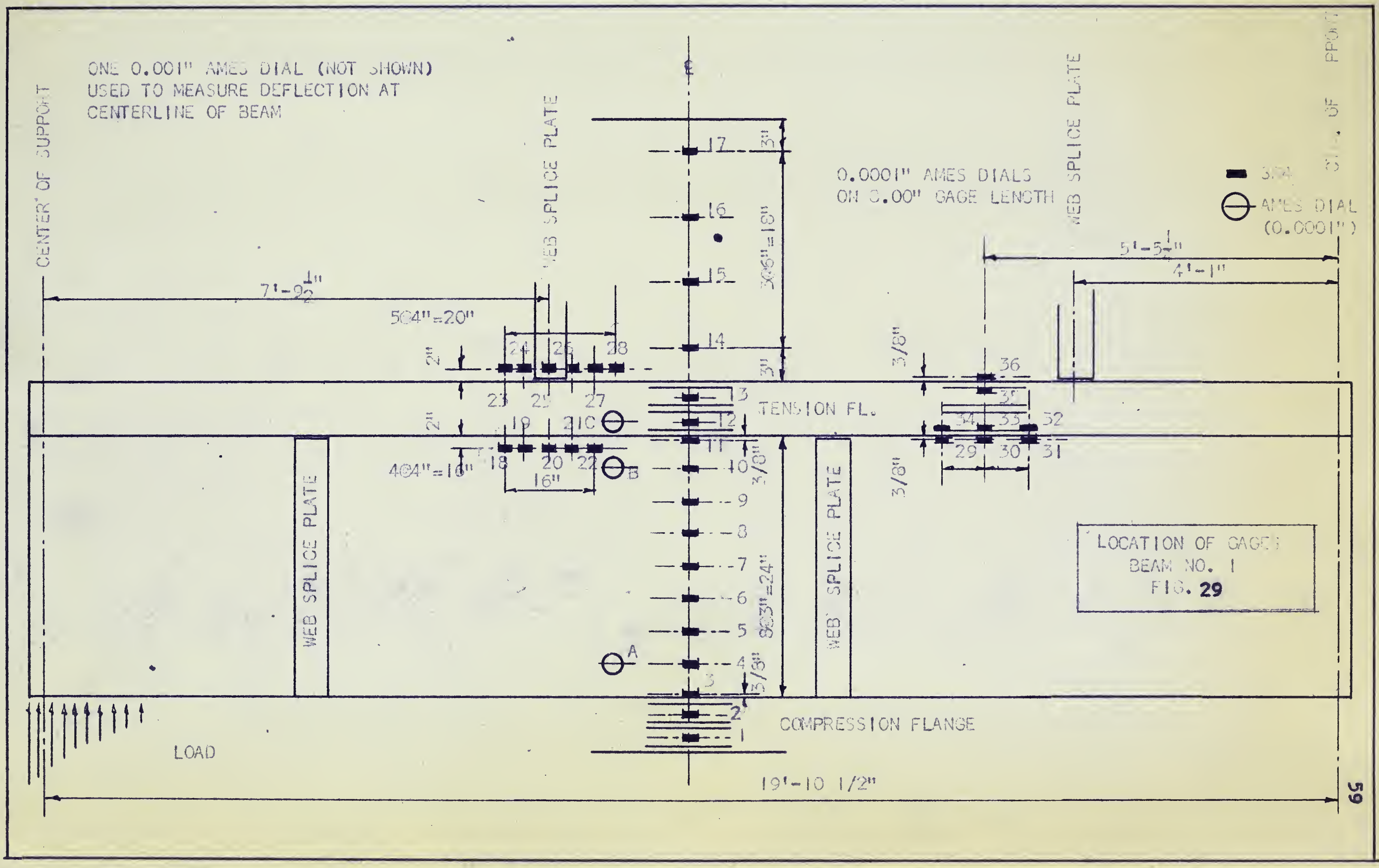
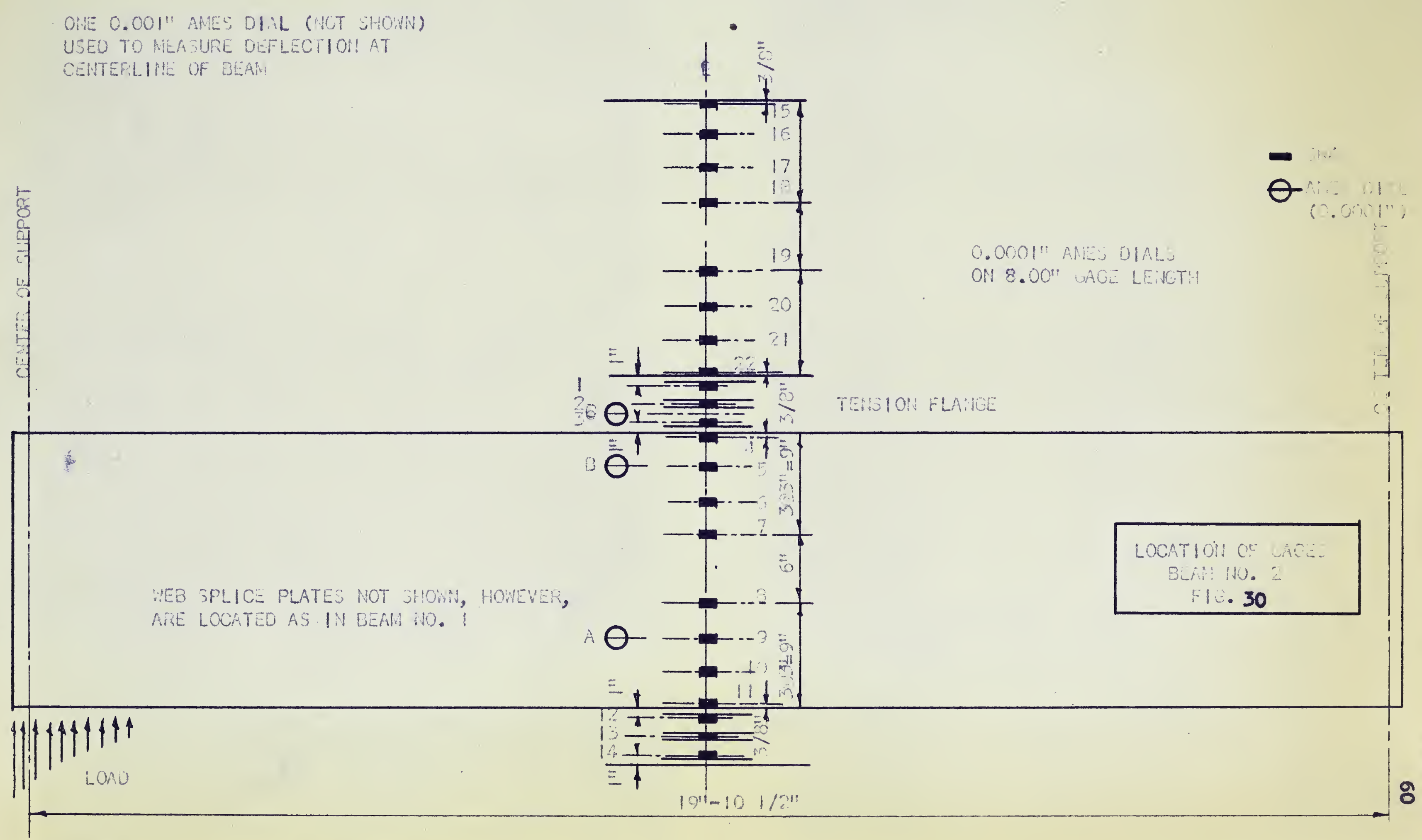


Fig.28 DIAL ASSEMBLY



LOCATION OF GAGES
BEAM NO. 1
FIG. 29


ONE 0.001" AMES DIAL (NOT SHOWN) USED TO MEASURE DEFLECTION AT CENTERLINE OF BEAM
SR-4
AMES DIAL (0.0001")
0.0001" AMES DIALS ON 8.00" GAGE LENGTH
TENSION FLANGE
WEB SPLICE PLATES NOT SHOWN, HOWEVER, ARE LOCATED AS IN BEAM NO. 1
CENTER OF SUPPORT
C. L. OF SUPPORT
LOAD
A
B
C
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
3/8"
6"
3 3/4" = 9"
1"
19'-10 1/2"

LOCATION OF GAGES
BEAM NO. 2
FIG. 30

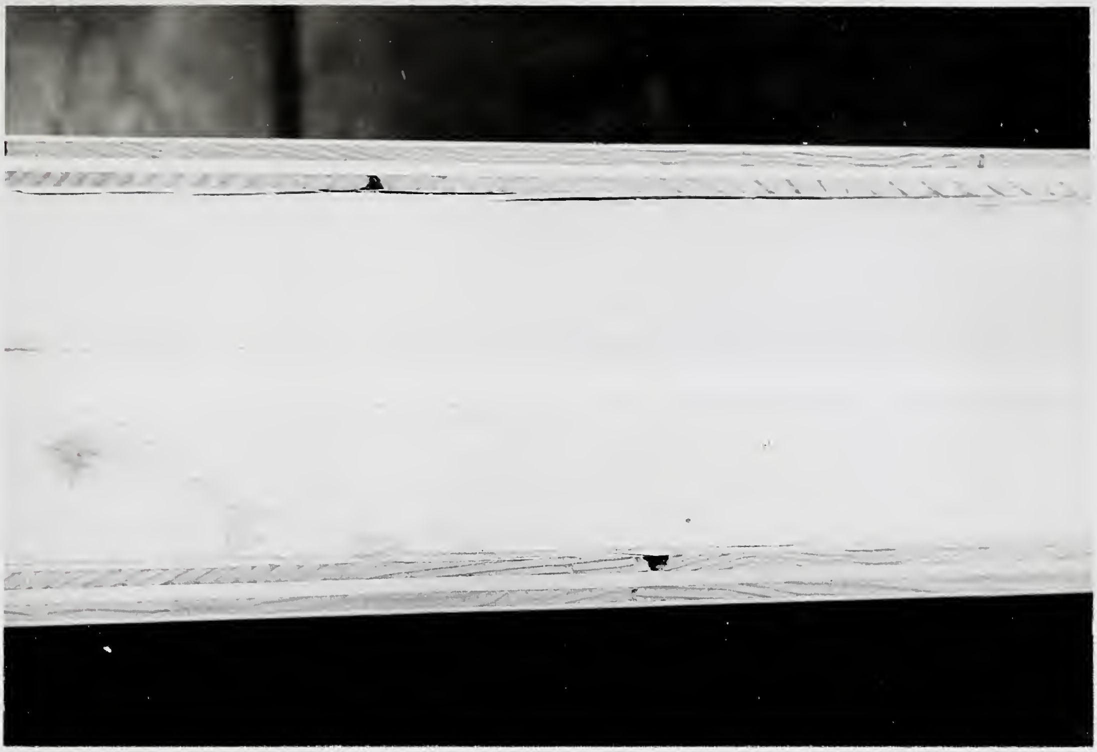
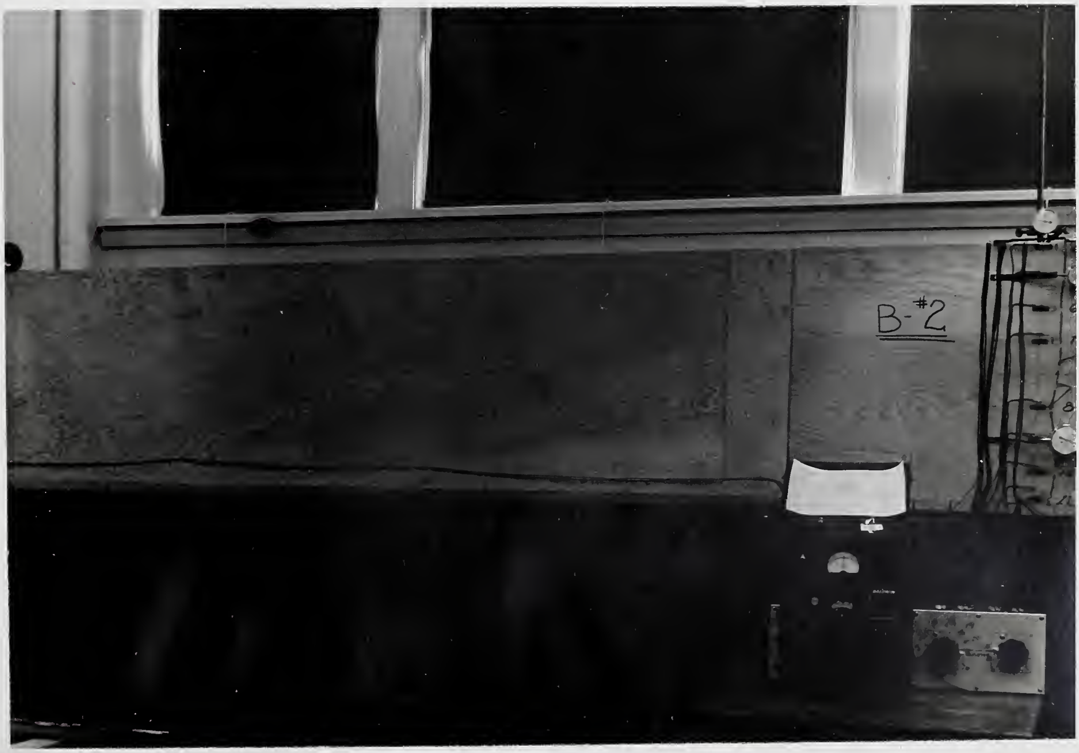


Fig. 31, Flange of Beam 2 on Face of Gages 1, 2 & 3- North 1/3 Pt.
Fig. 32, Beam 2 Under Load.



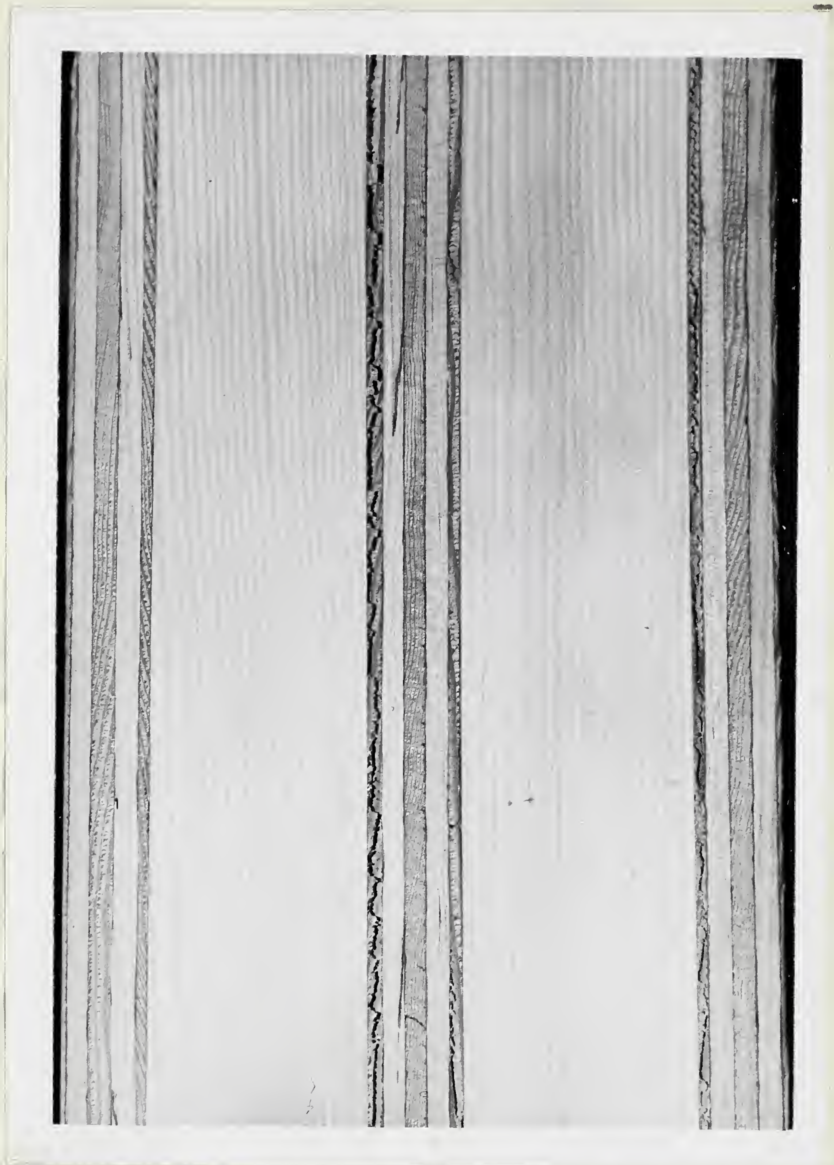


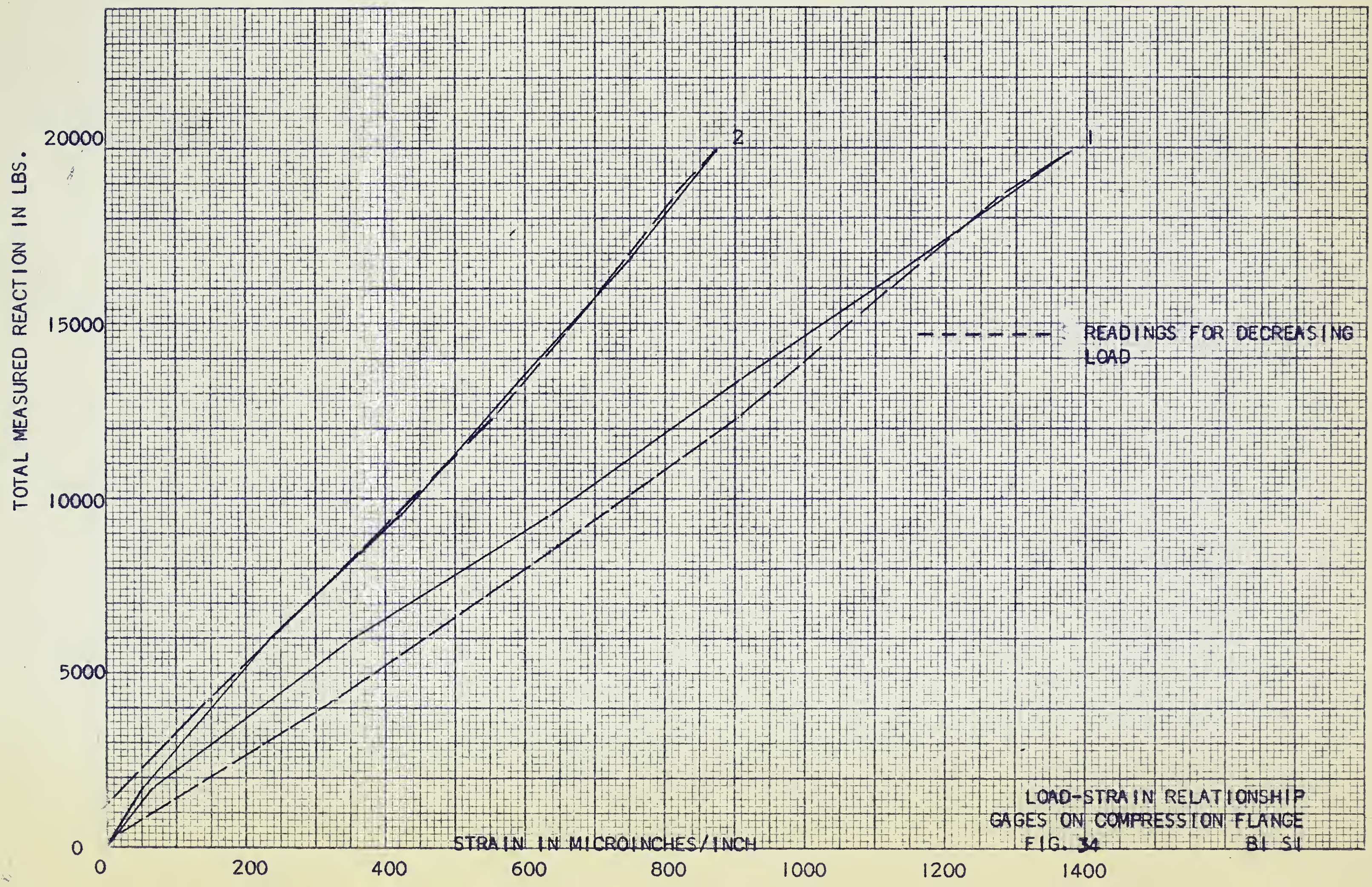
Fig. 33 Typical Cracks in Plywood at End Stiffeners in Beams. (This N-end B-1.)

V Presentation of Results

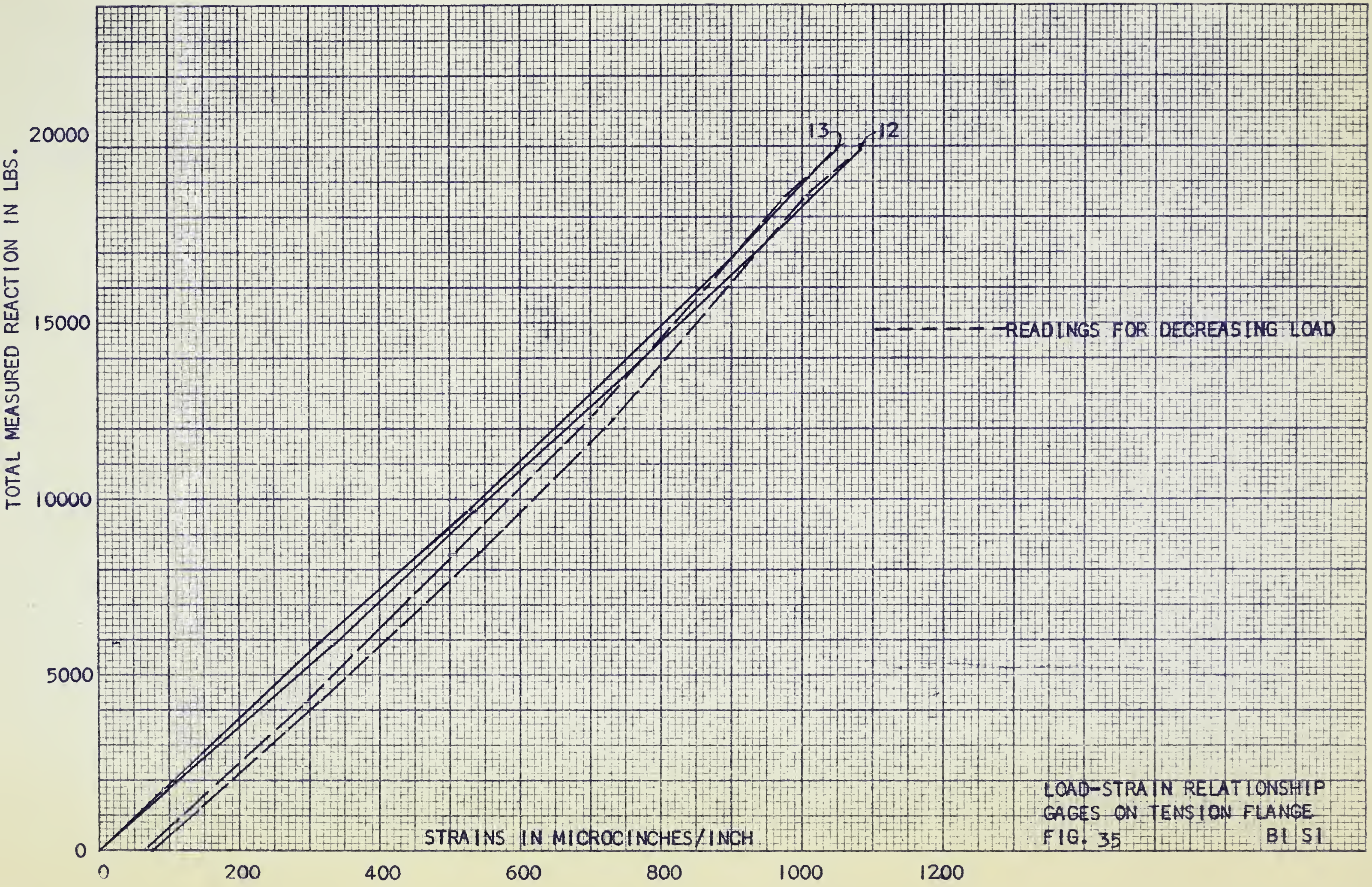
The major portion of the data is presented graphically in the following forms:

	CYCLE	FIGURES
Load versus strain	B1 S1	34, 35, 36 and 37
	B1 S2	39, 40 and 41
	B1 S3	43
	B2 S1	49
	B2 S2	50, 51 and 52
Load versus deflection	B1 S1	38
	B1 S2	42
	B2 S2	53
Strain distribution over the depth of the beams at midspan	B1 S1	44
	B1 S2	45
	B1 S3	46
	B2 S1	54
	B2 S2	55
	B2 S5	56
Strain distribution along the beams in the vicinity of the web splices	B1 S1	59
	B1 S2	61 and 63
Load versus strain in the vicinity of the web splices	B1 S1	60
	B1 S2	62
Photographs of beam flanges at midspan after tests	Beam No. 1	47 and 47
	Beam No. 2	57 and 58
Load versus strain comparing SR-4 and mechanical dial readings	B1 S1	64
	B1 S2	65
	B2 S2	66

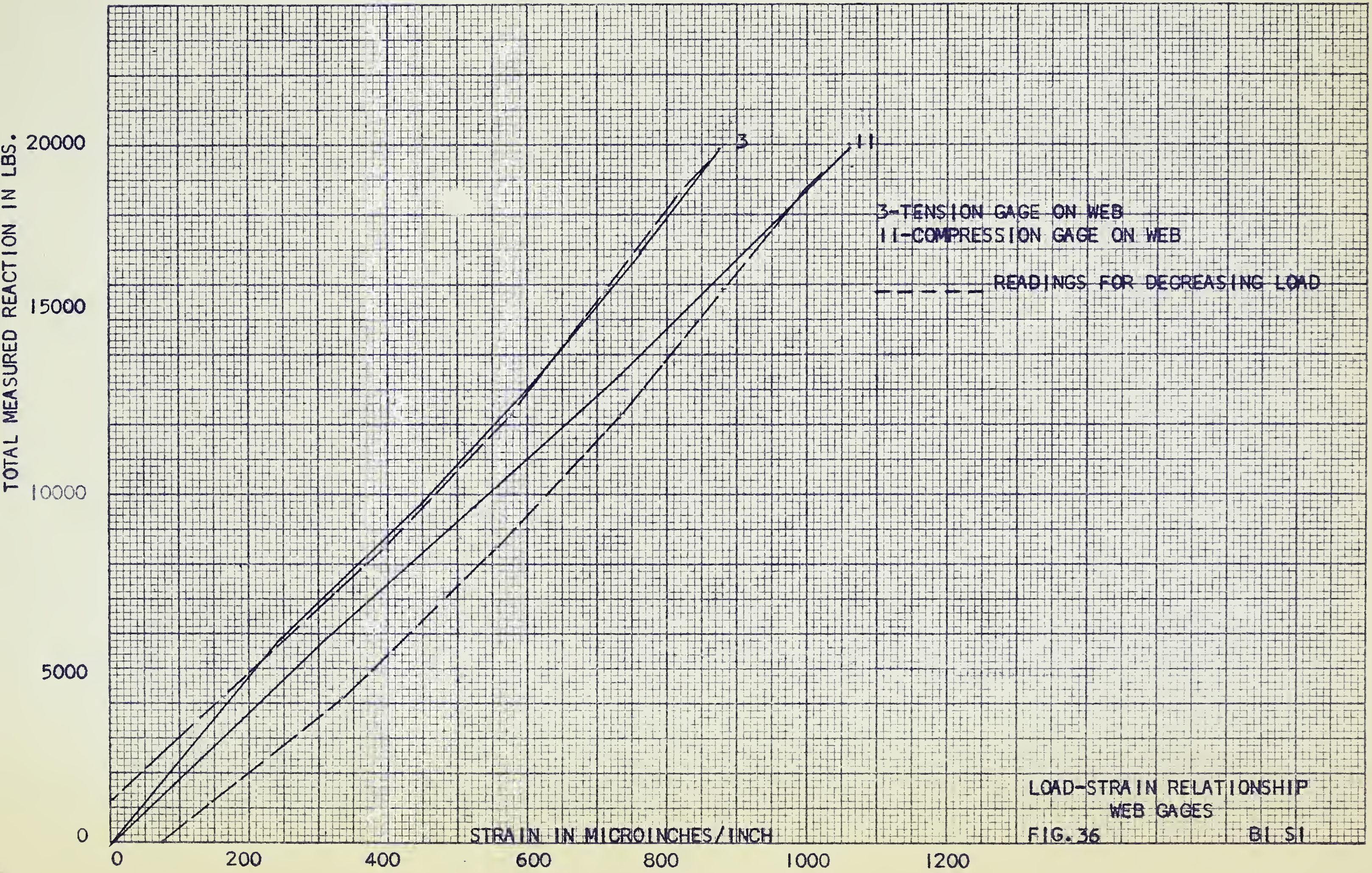
The theoretical wood strains used for comparison with the observed strains were computed from standard engineering formulae assuming the modulus of elasticity of 1.8×10^6 pounds per square inch and the net moment of inertia of the sections involved.



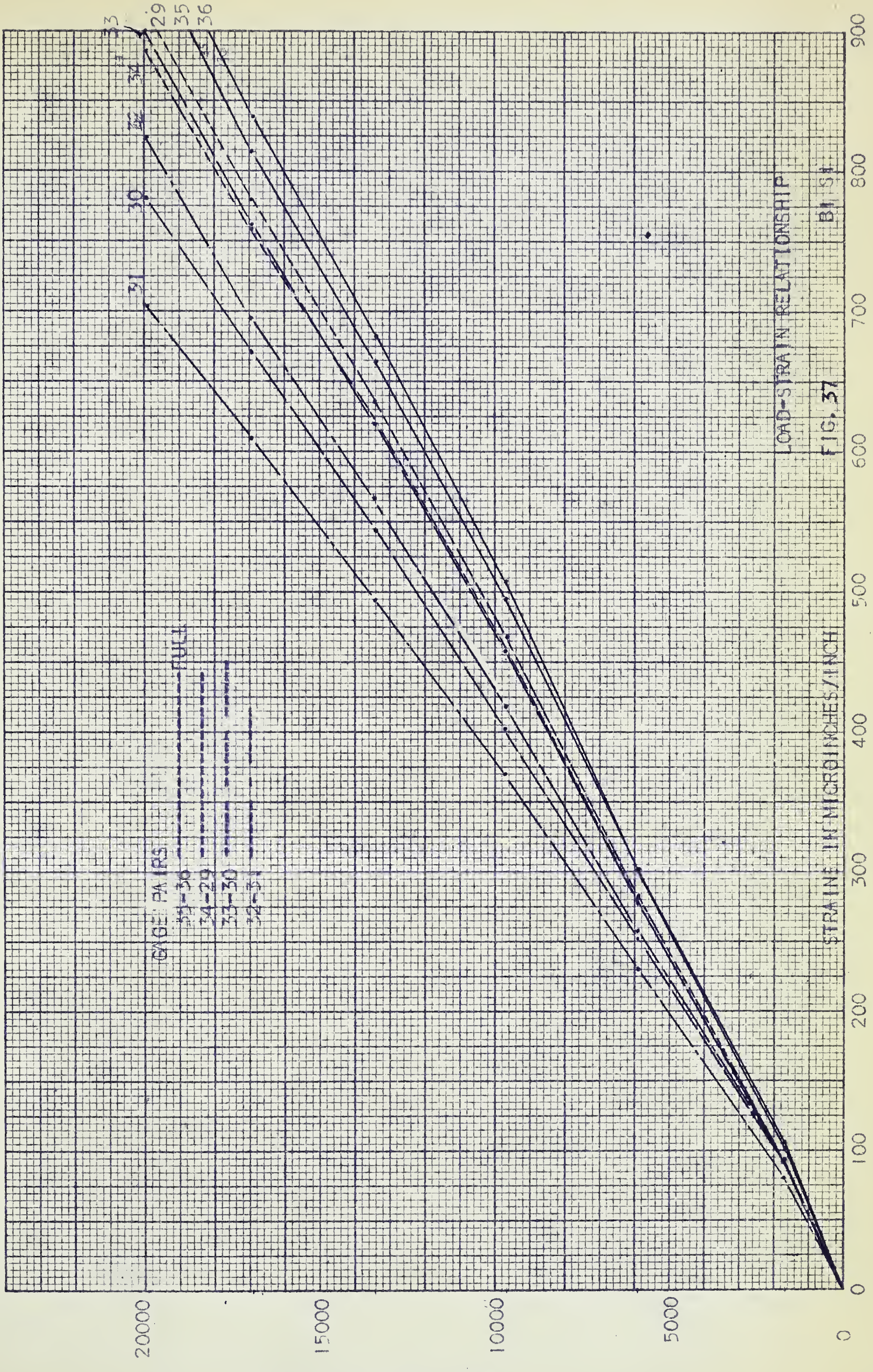
LOAD-STRAIN RELATIONSHIP
GAGES ON COMPRESSION FLANGE
FIG. 34
BI SI



LOAD-STRAIN RELATIONSHIP
GAGES ON TENSION FLANGE
FIG. 35 BI S1

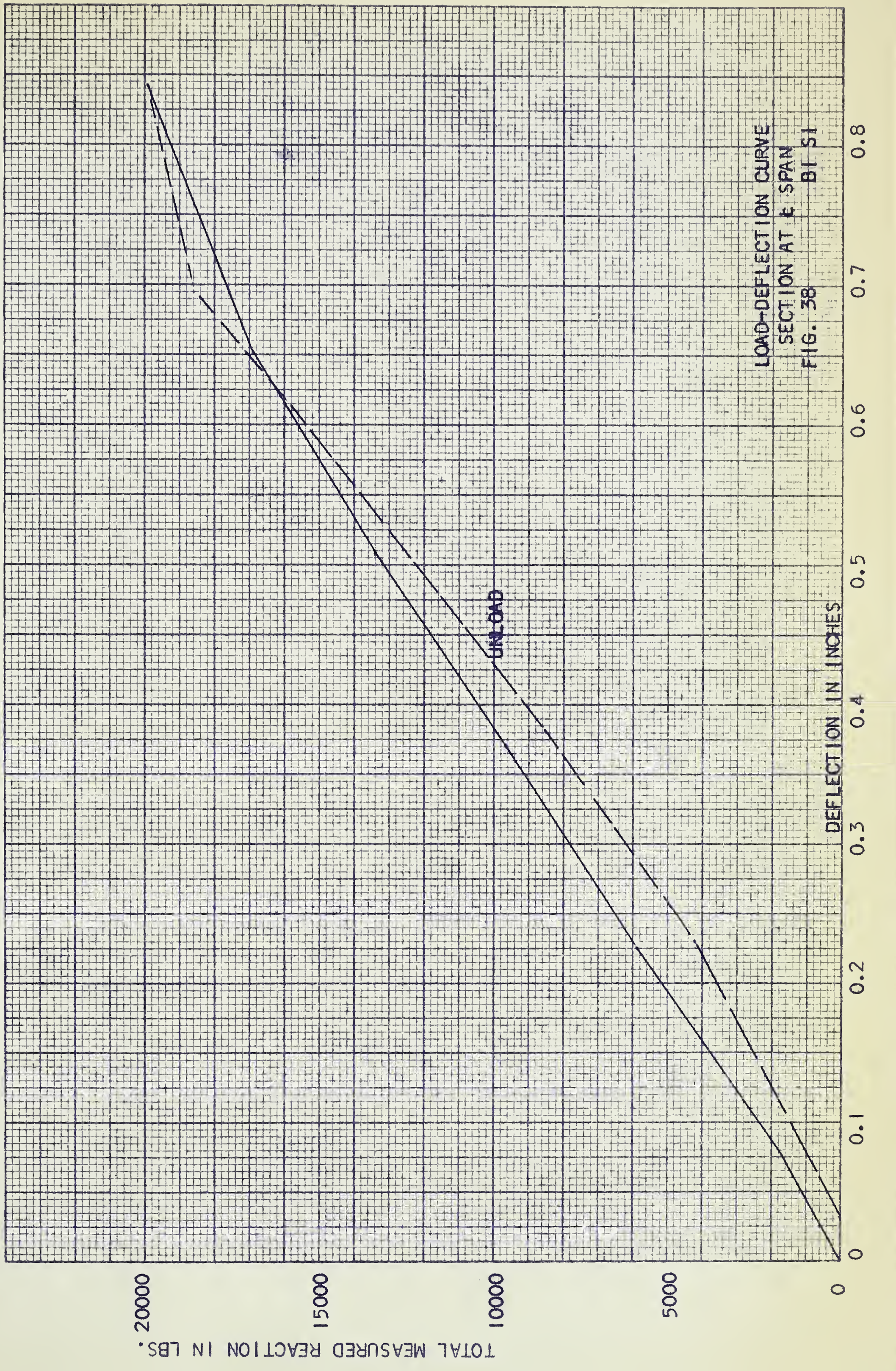


LOAD-STRAIN RELATIONSHIP
WEB GAGES
FIG. 36
BI SI

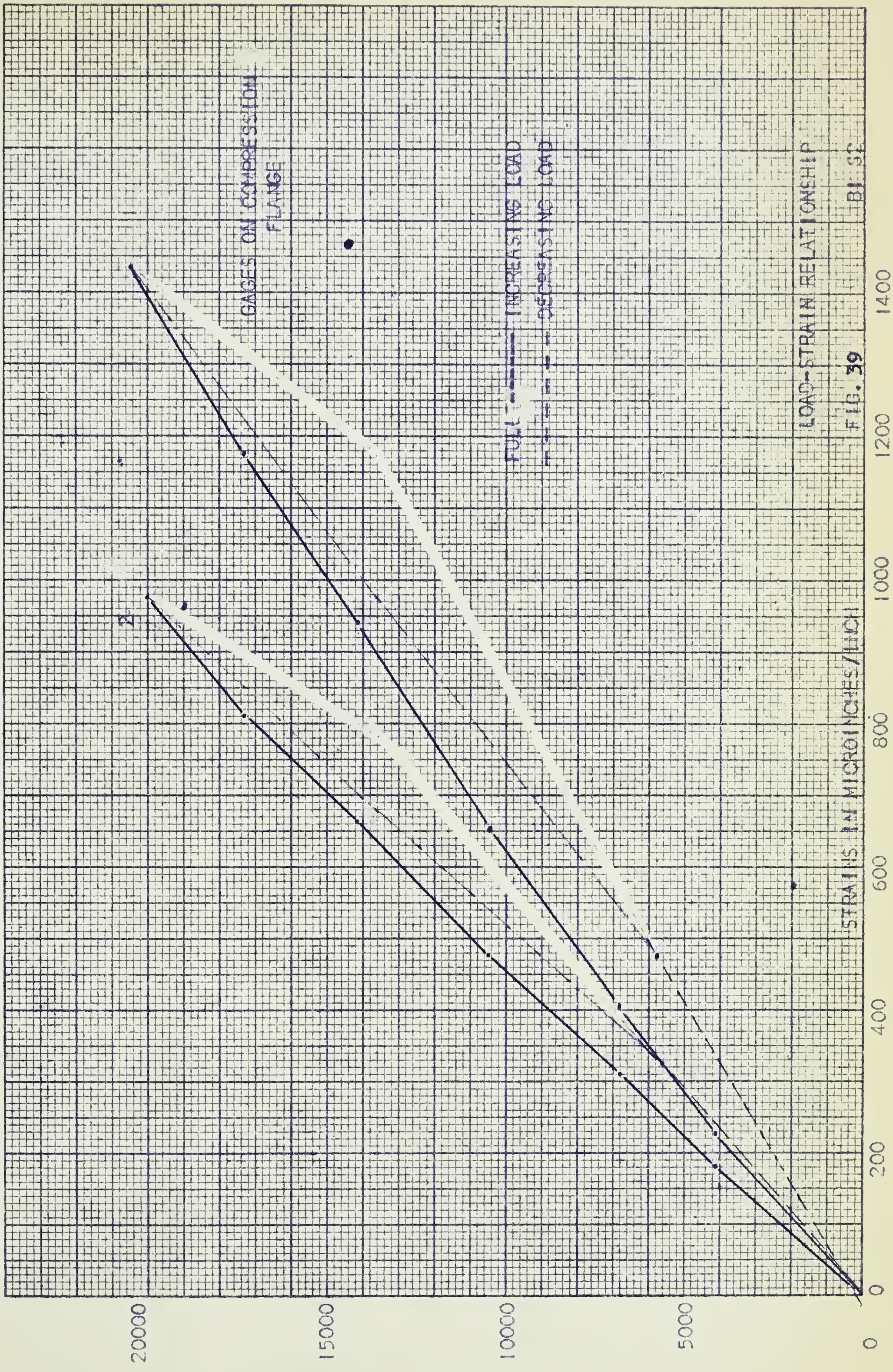


LOAD-STRAIN RELATIONSHIP

FIG. 37 B1 S1

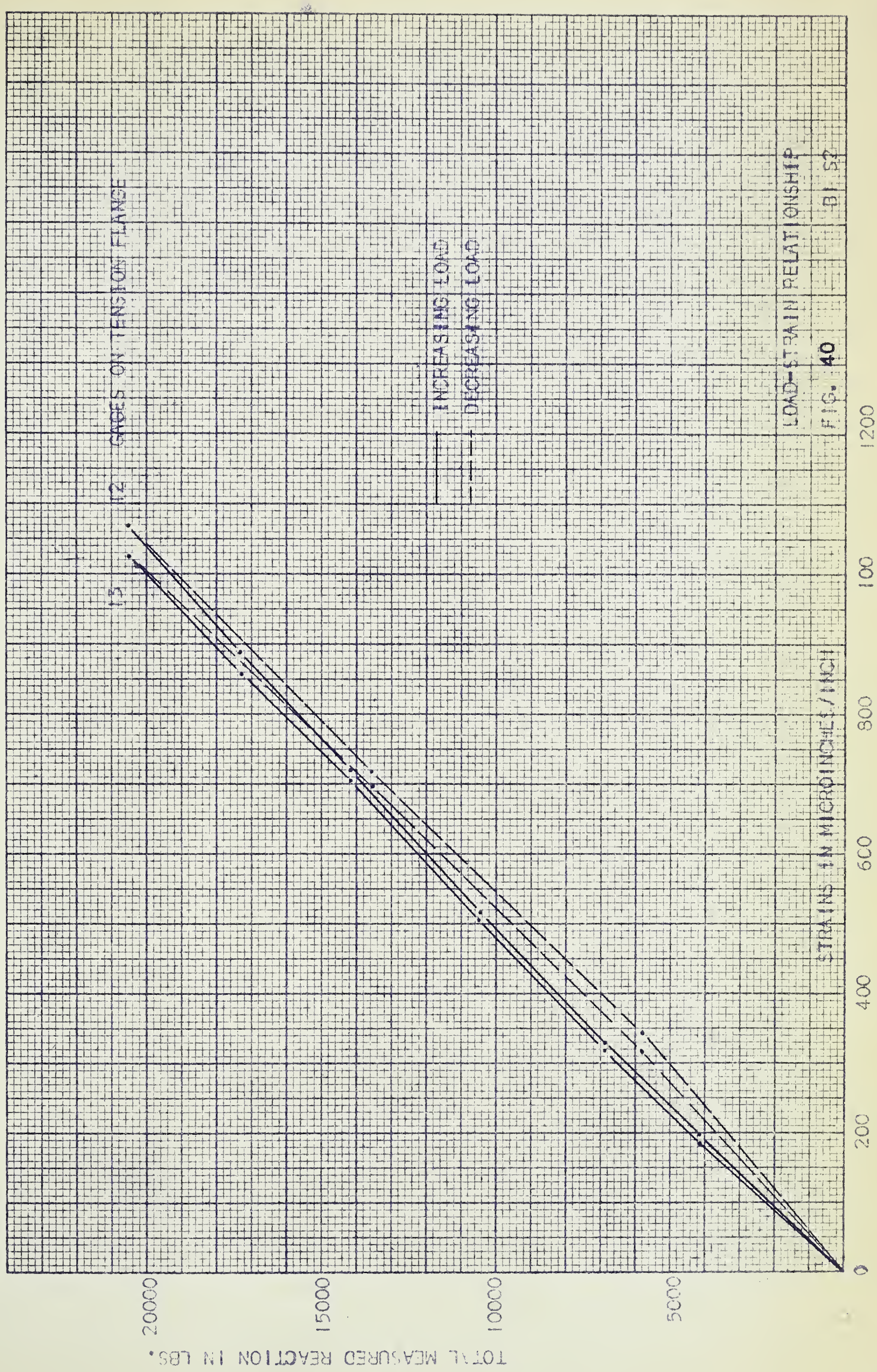


LOAD-DEFLECTION CURVE
SECTION AT ℄ SPAN
FIG. 38 BI S1



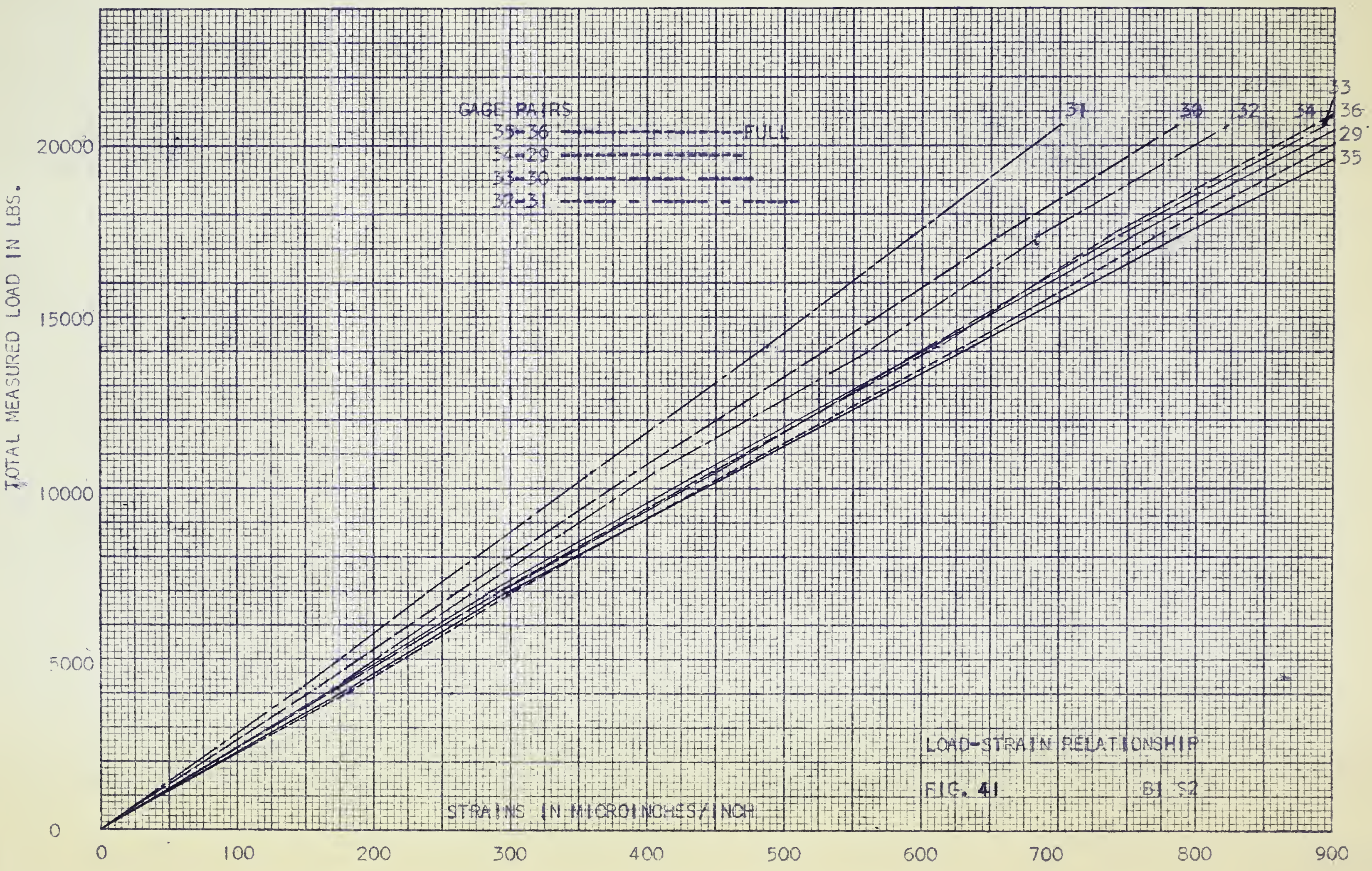
LOAD-STRAIN RELATIONSHIP

FIG. 39 BI-3E



LOAD-STRAIN RELATIONSHIP

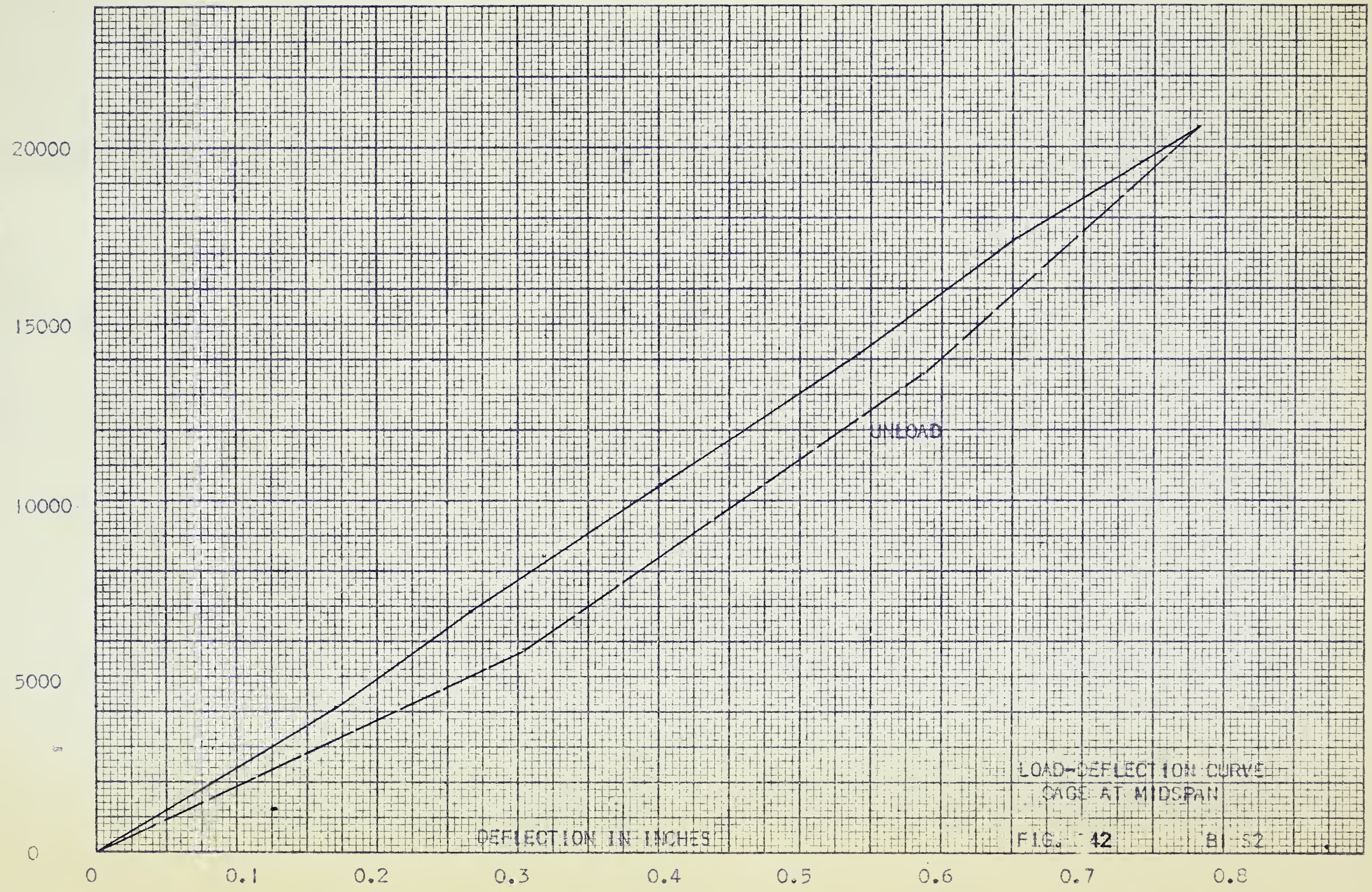
FIG. 40 B1 S2



LOAD-STRAIN RELATIONSHIP

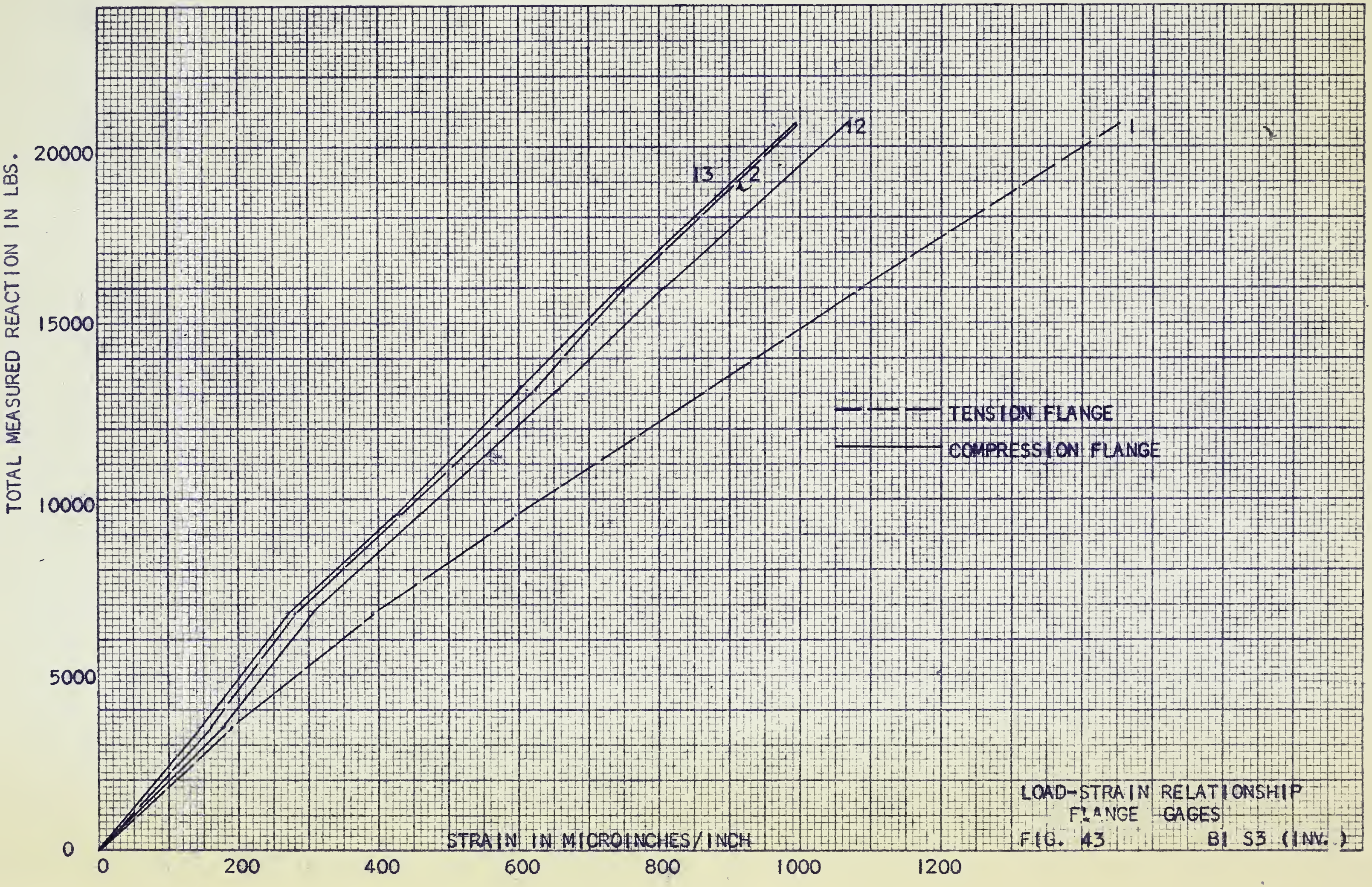
FIG. 41

B1 S2

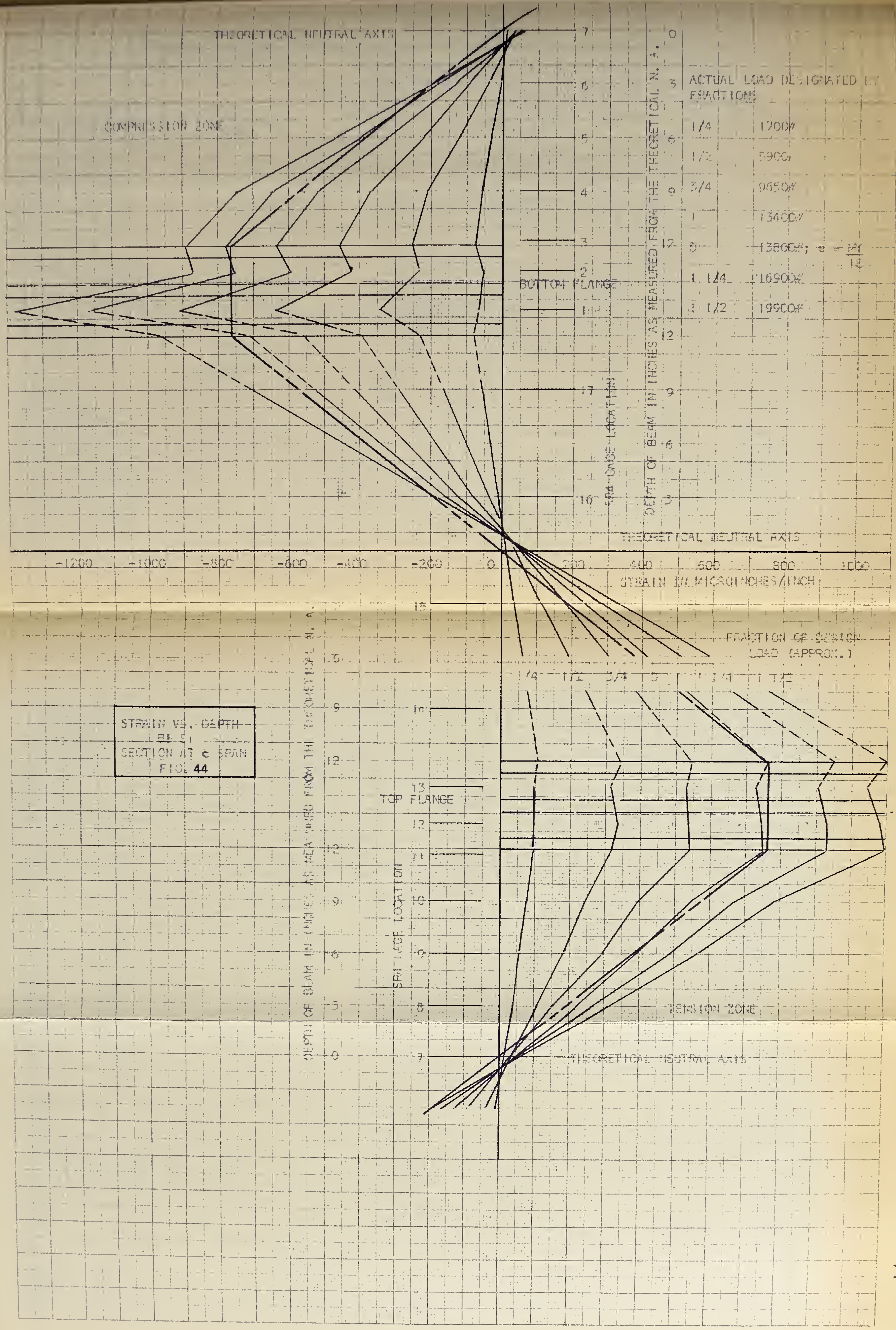


LOAD-DEFLECTION CURVE
GAGE AT MIDSPAN

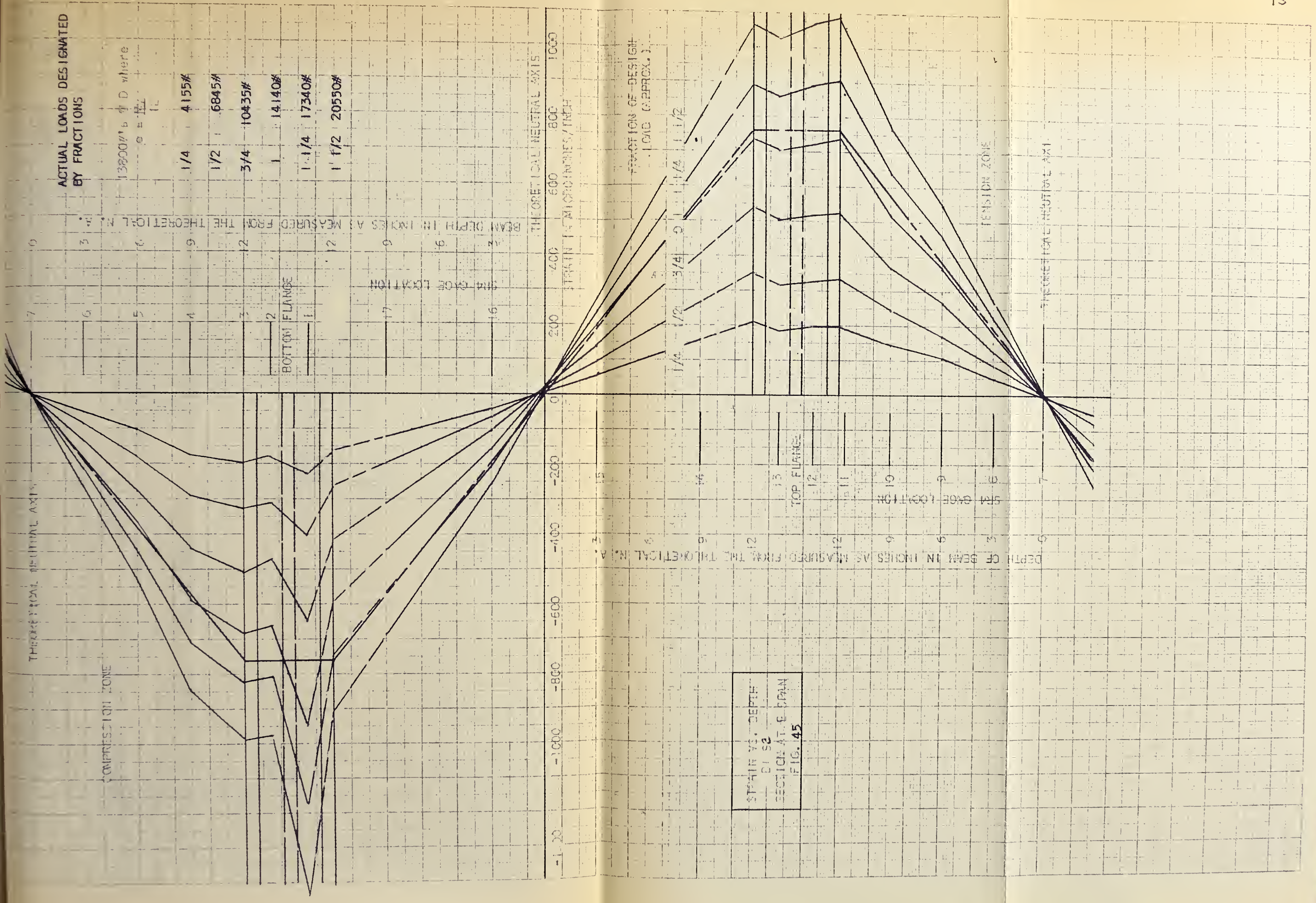
FIG. 42



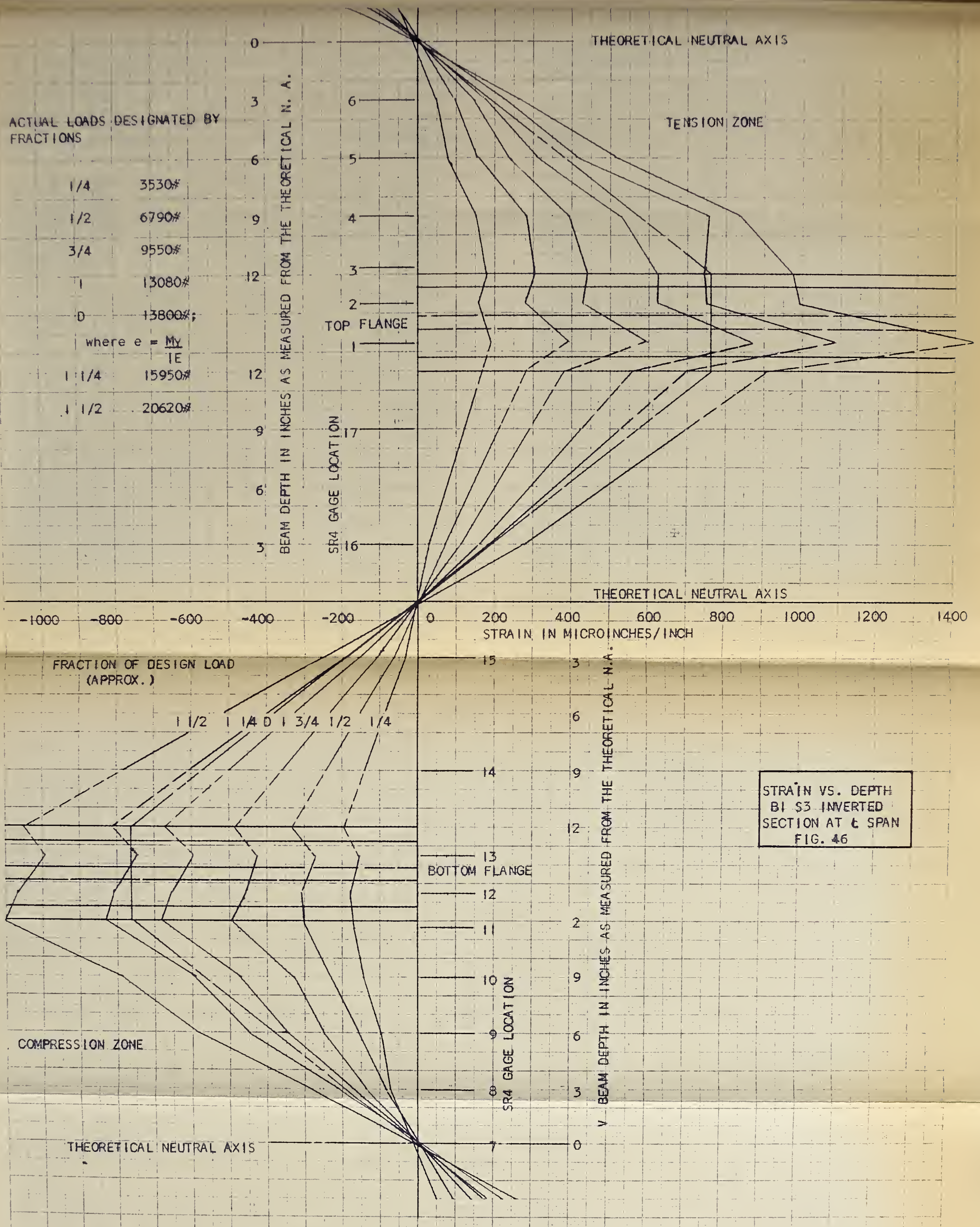
LOAD-STRAIN RELATIONSHIP
FLANGE GAGES
FIG. 43 BI S3 (INV.)



STRAIN VS. DEPTH
B-S1
SECTION AT ℄ SPAN
FIG. 44



STRAIN VS. DEPTH
DI S2
SECTION AT ℄ SPAN
FIG. 45



STRAIN VS. DEPTH
BI S3 INVERTED
SECTION AT ℄ SPAN
FIG. 46

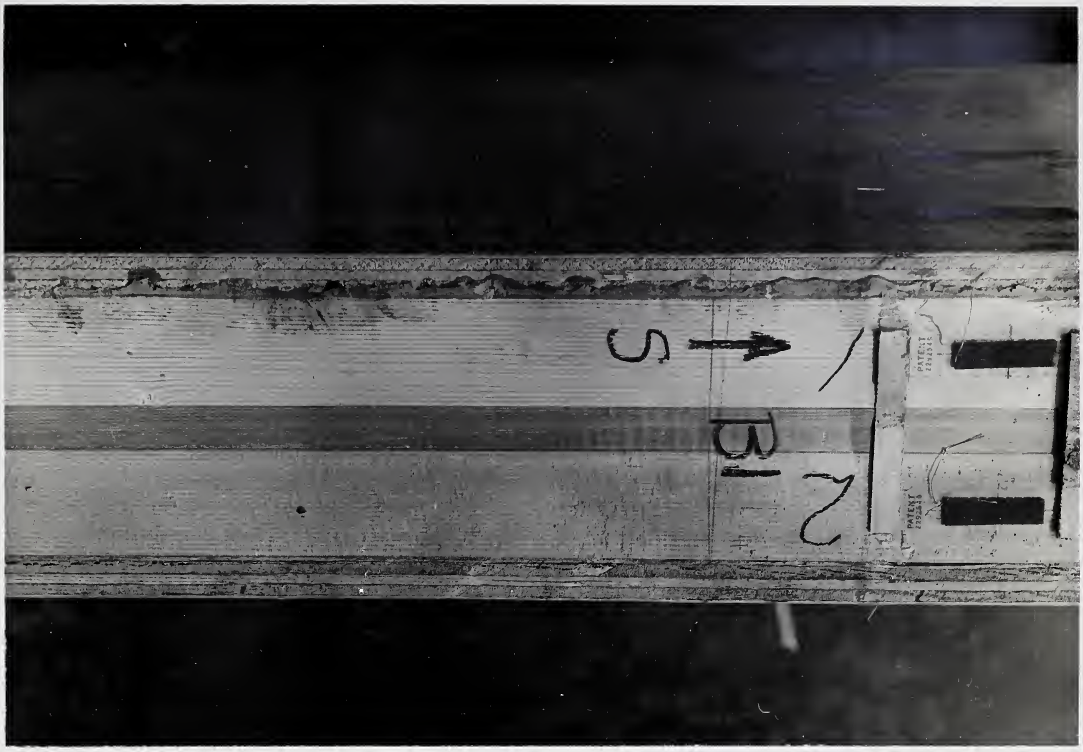
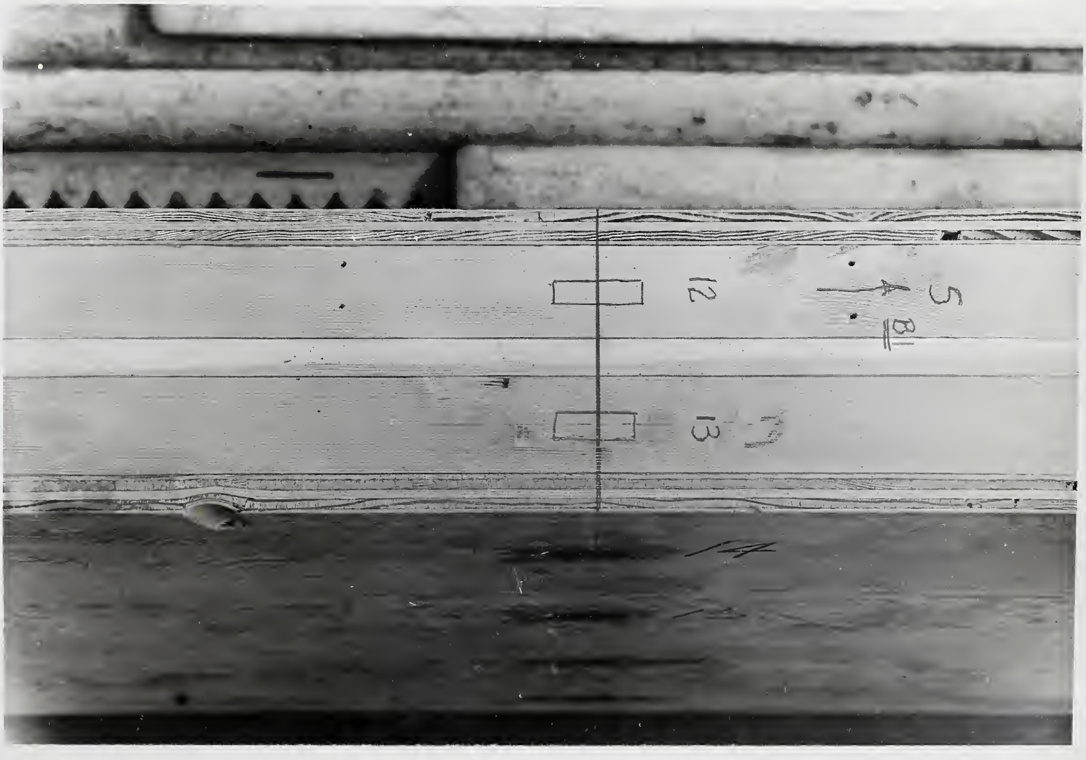
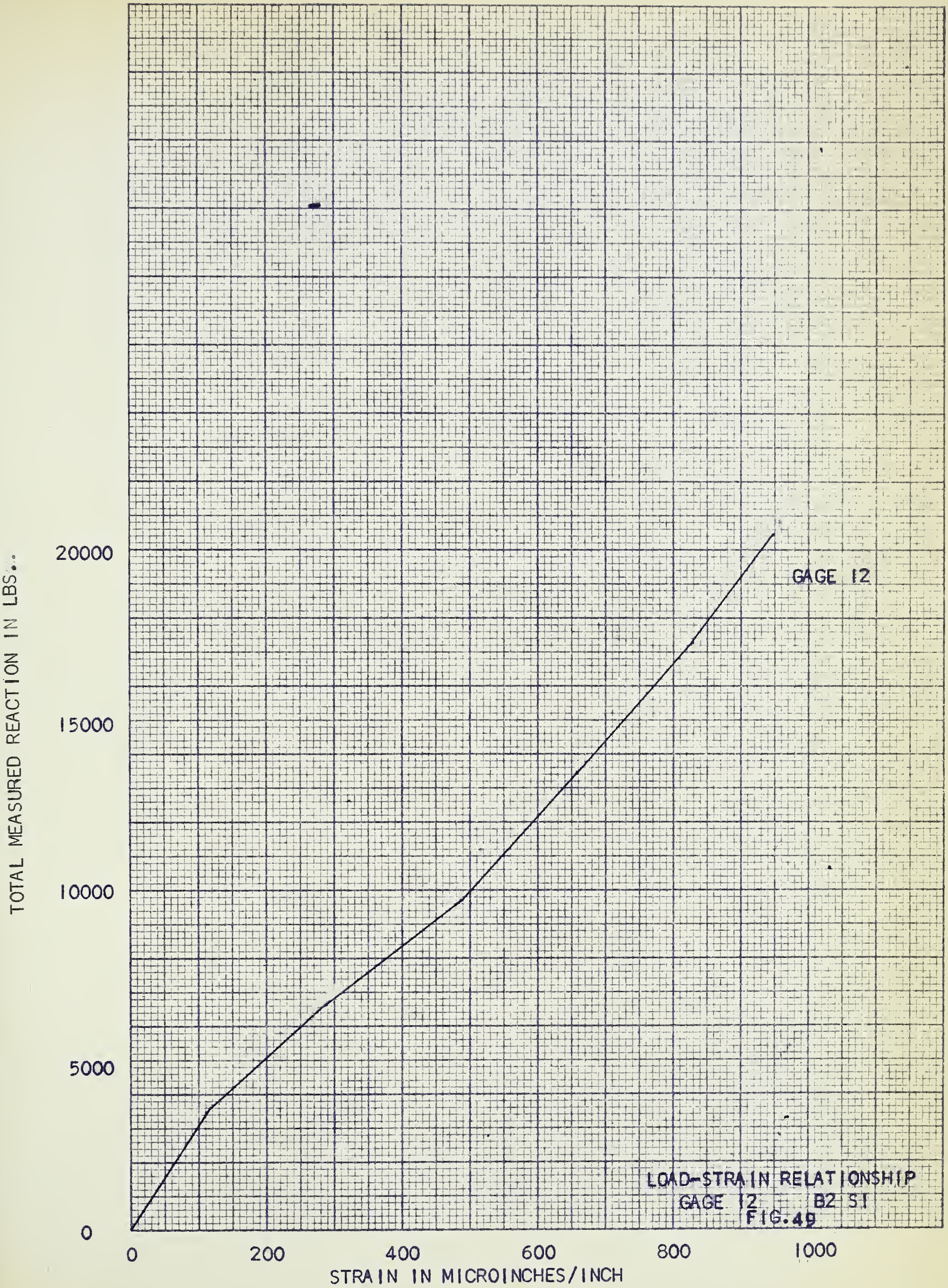
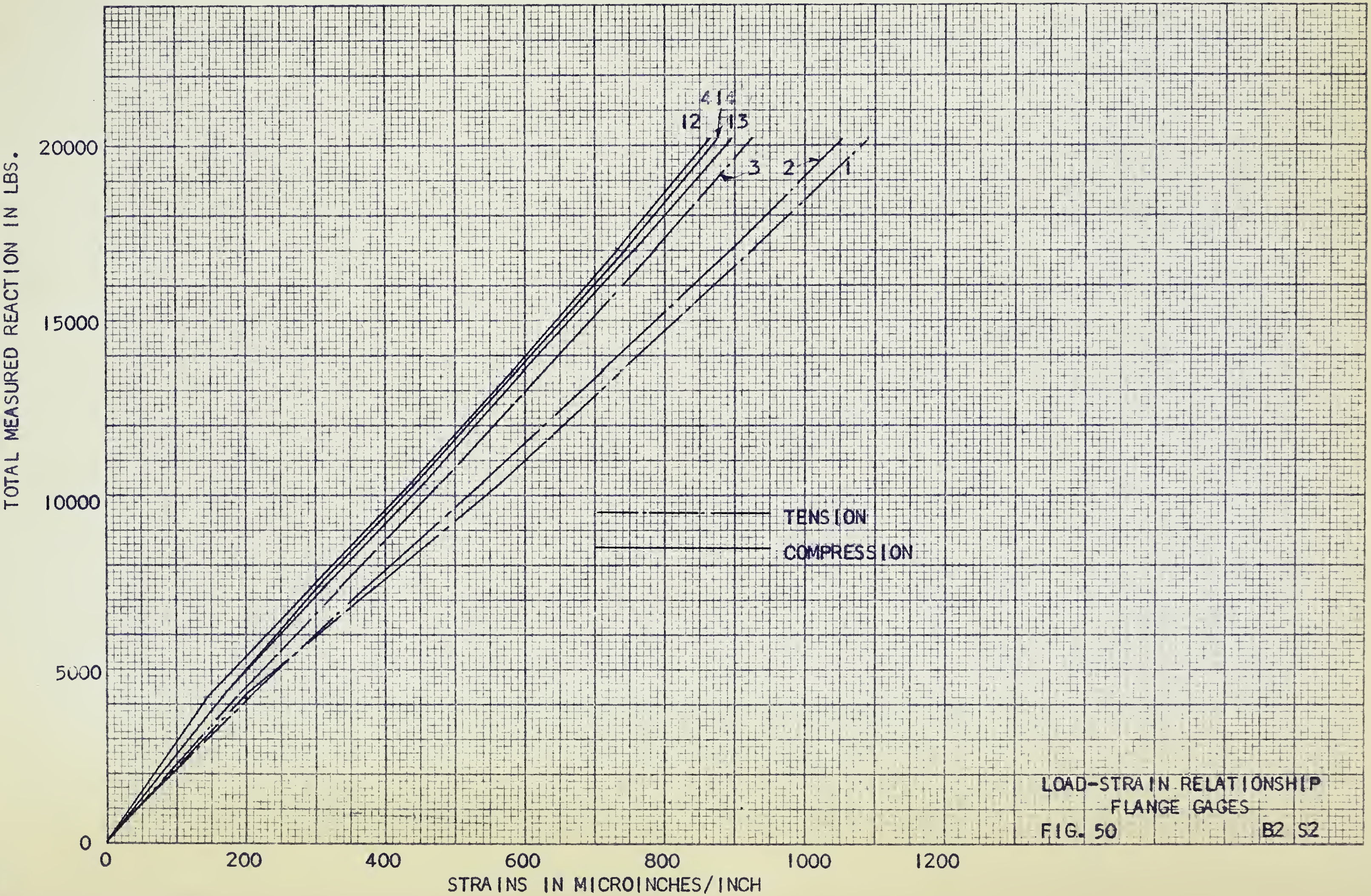


Fig. 47, Flange of Beam 1 at Gage Positions 1 & 2.
Fig. 48, Flange of Beam 1 at Gage Positions 12 & 13.



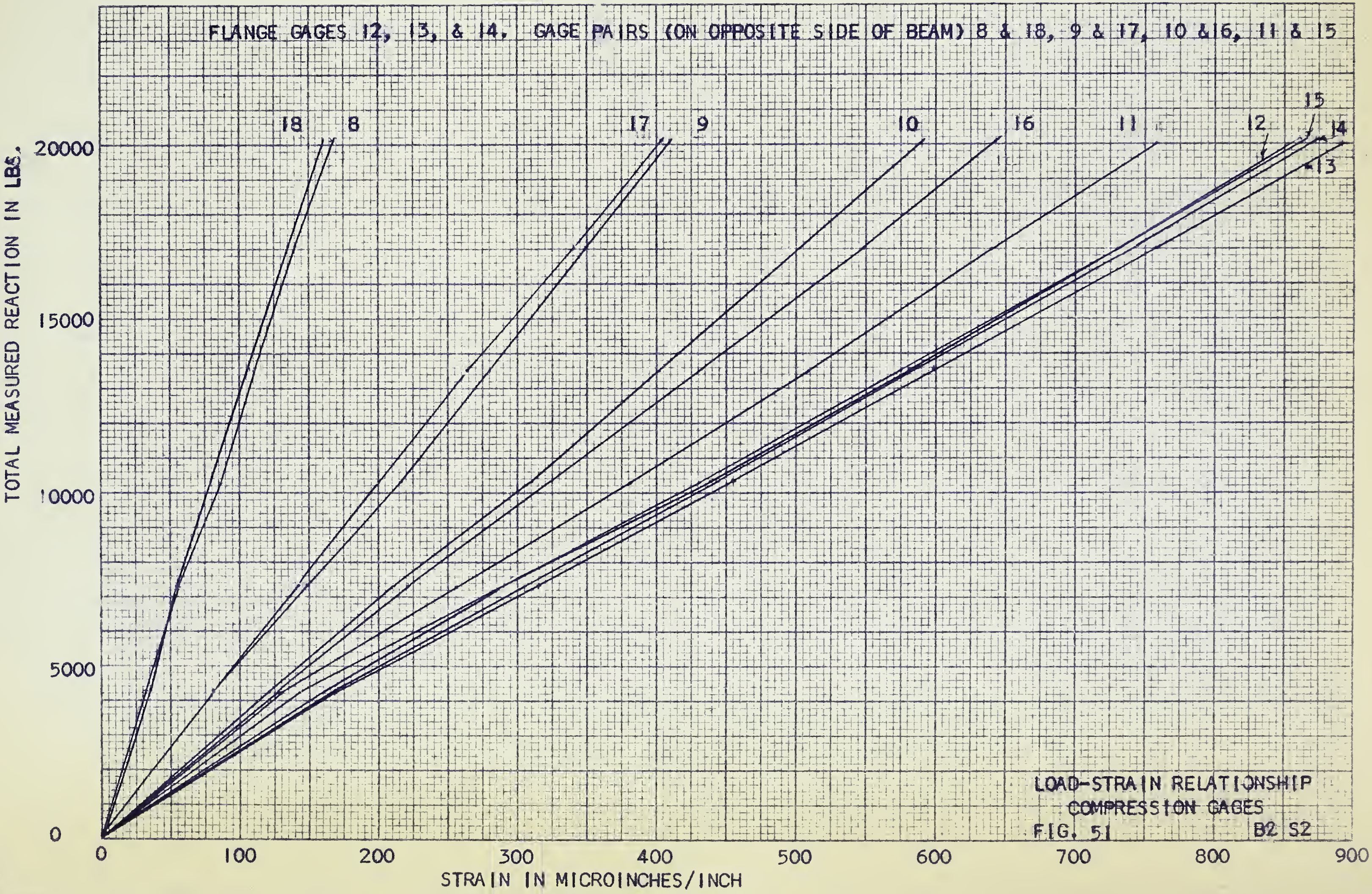


LOAD-STRAIN RELATIONSHIP
GAGE 12 B2 ST
FIG.49

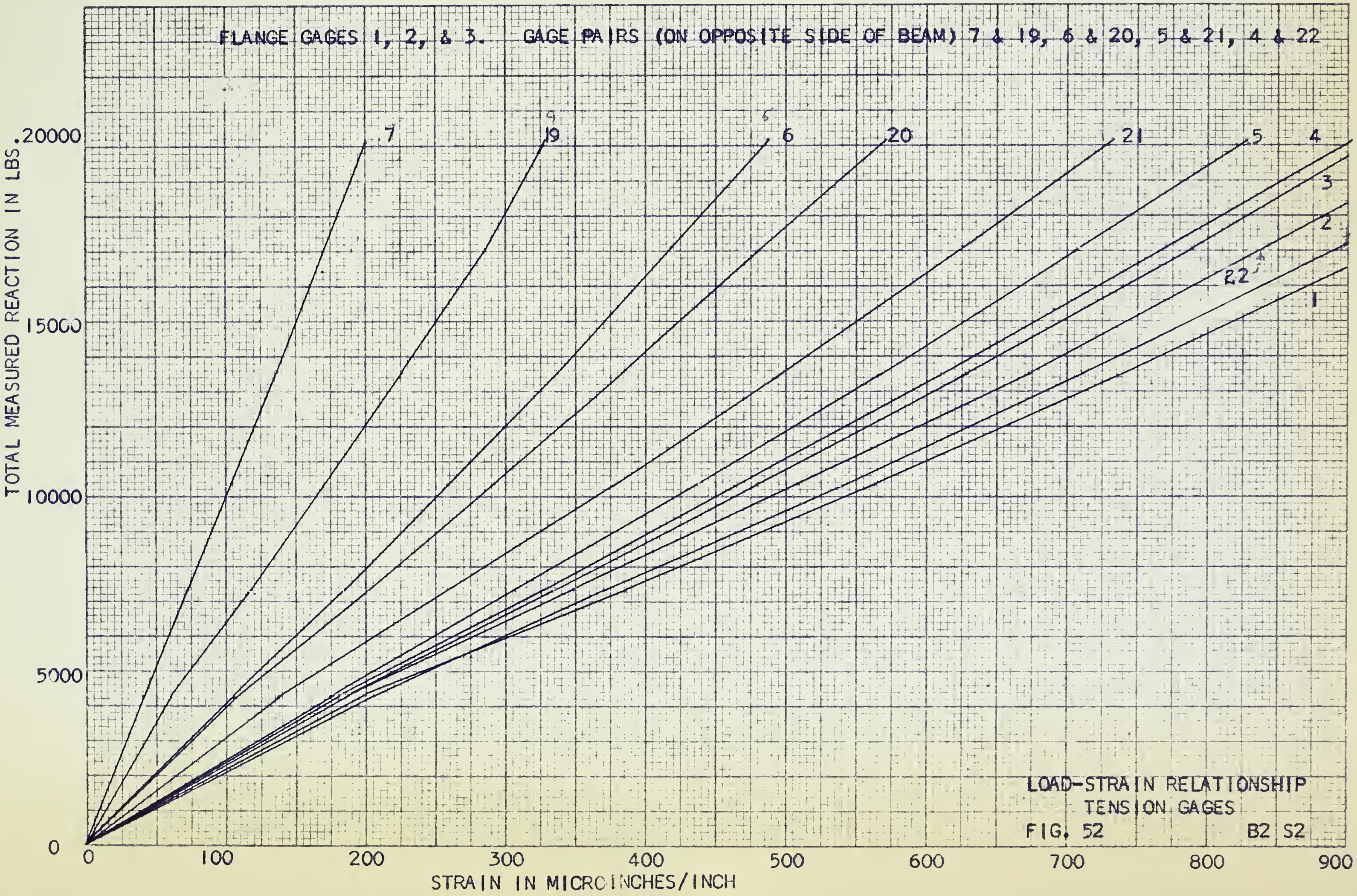


LOAD-STRAIN RELATIONSHIP
FLANGE GAGES

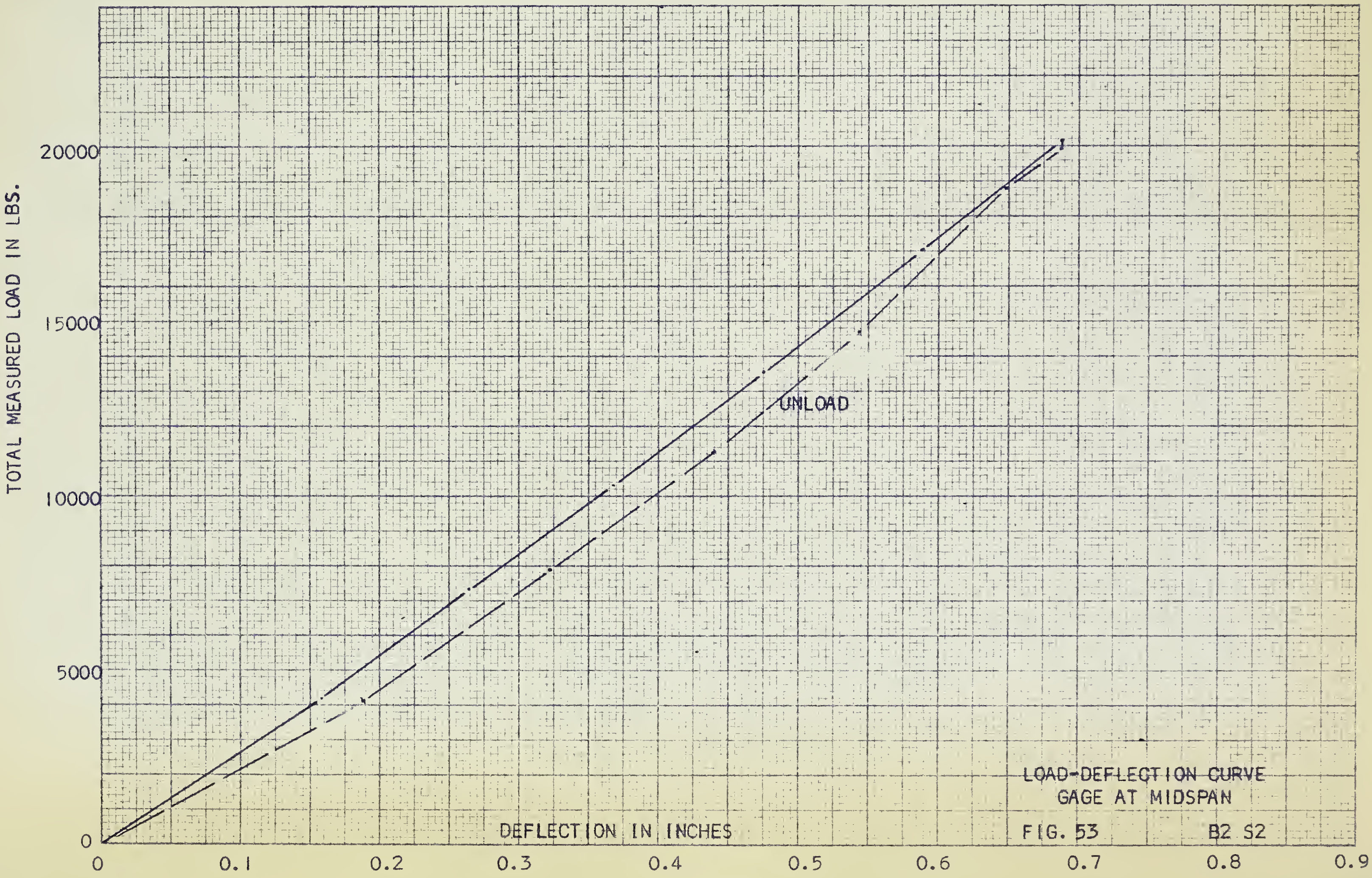
FIG. 50 B2 S2



LOAD-STRAIN RELATIONSHIP
COMPRESSION GAGES
FIG. 51

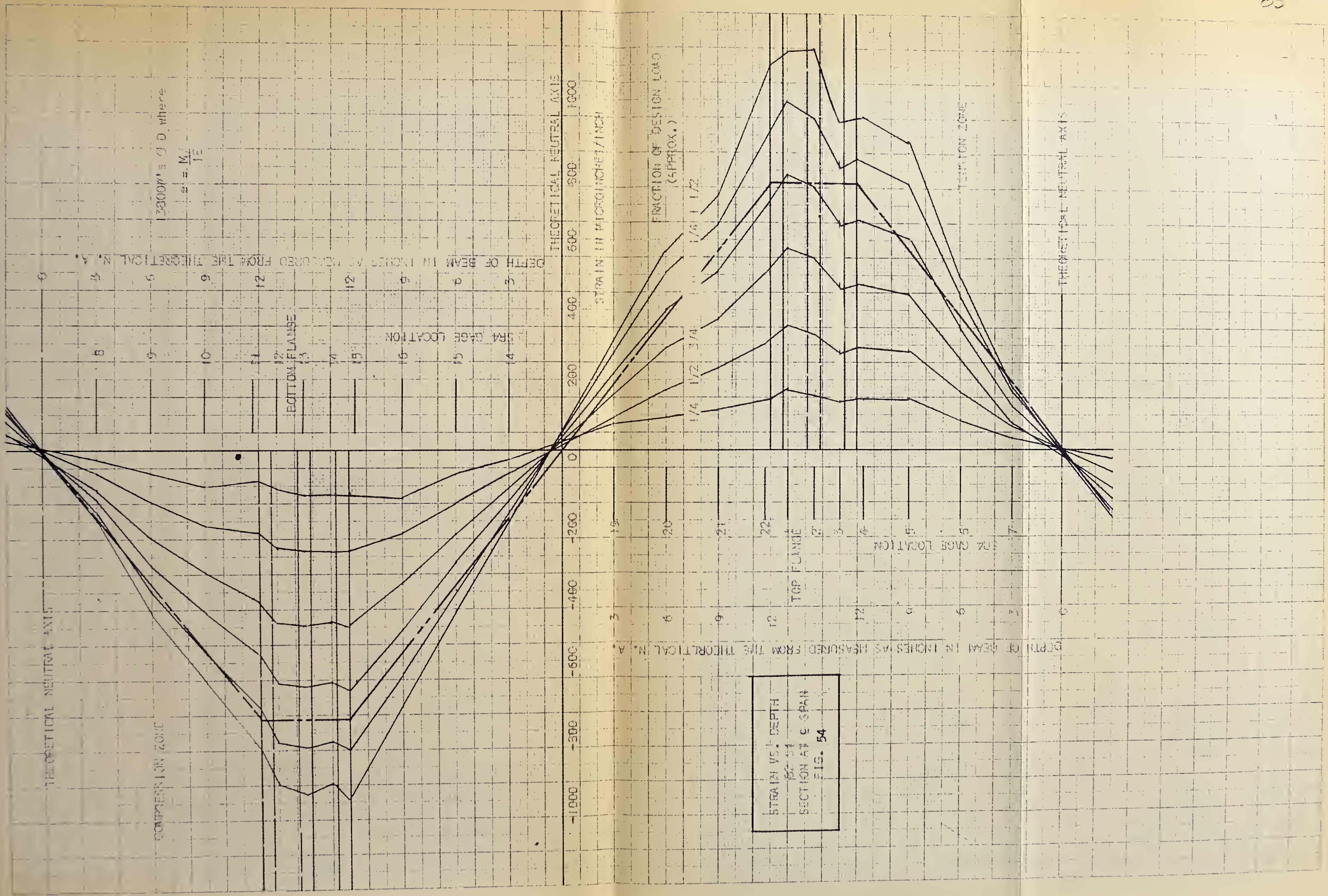


LOAD-STRAIN RELATIONSHIP
TENSION GAGES
FIG. 52 B2 S2

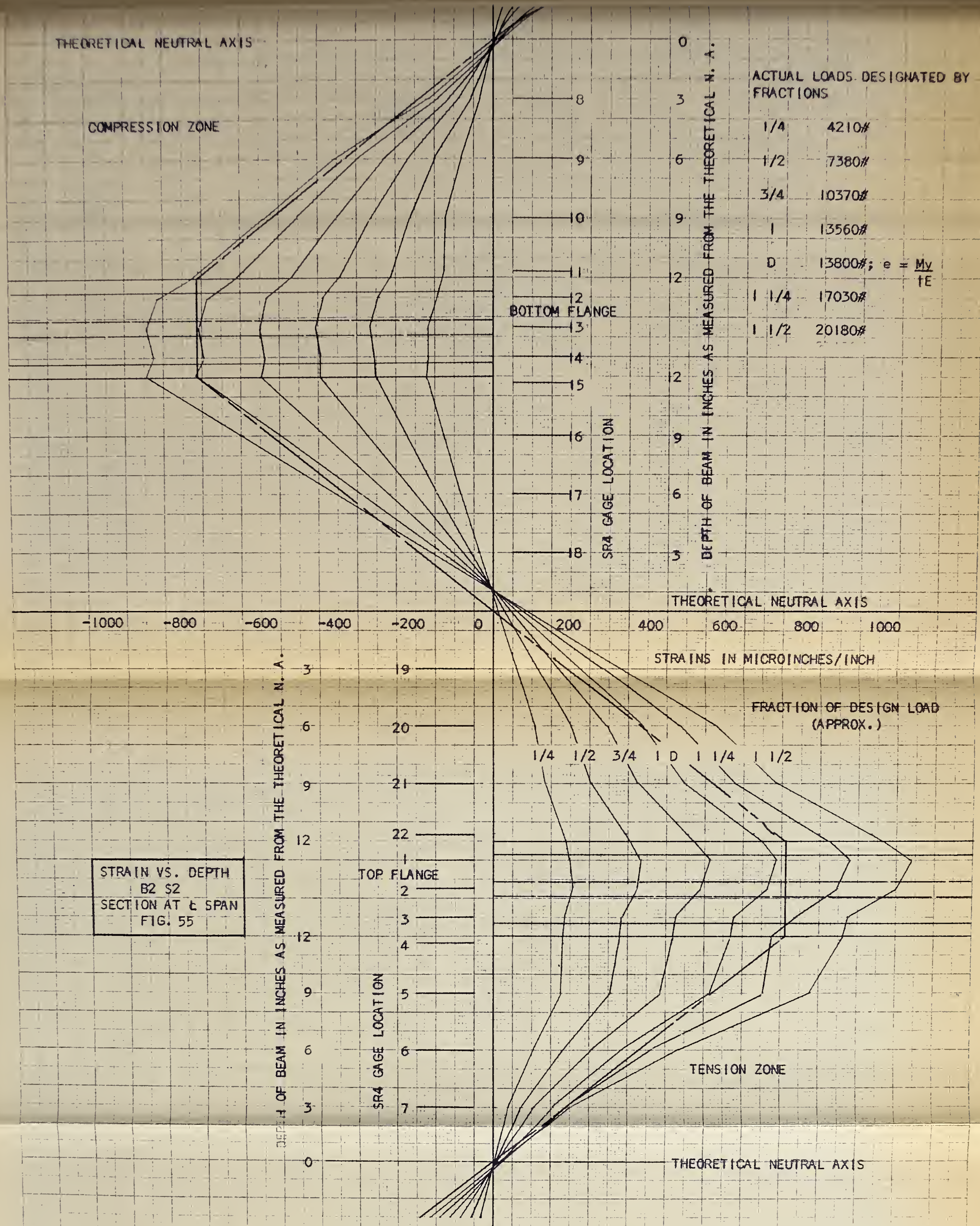


LOAD-DEFLECTION CURVE
GAGE AT MIDSPAN

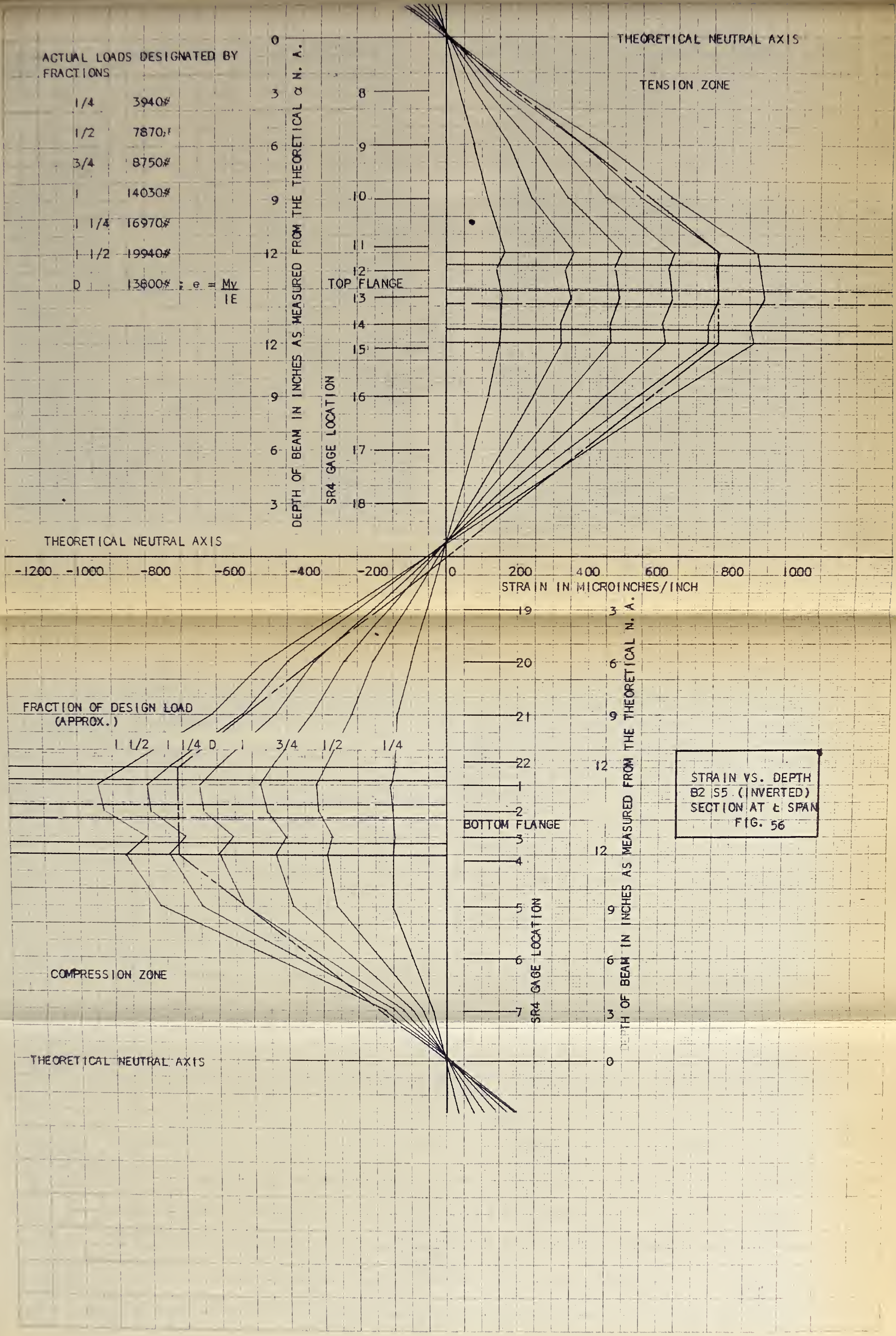
FIG. 53 B2 S2



STRAIN VS. DEPTH
B2 S1
SECTION AT ℄ SPAN
FIG. 54



STRAIN VS. DEPTH
B2 S2
SECTION AT ℄ SPAN
FIG. 55



STRAIN VS. DEPTH
B2 S5 (INVERTED)
SECTION AT ℄ SPAN
FIG. 56

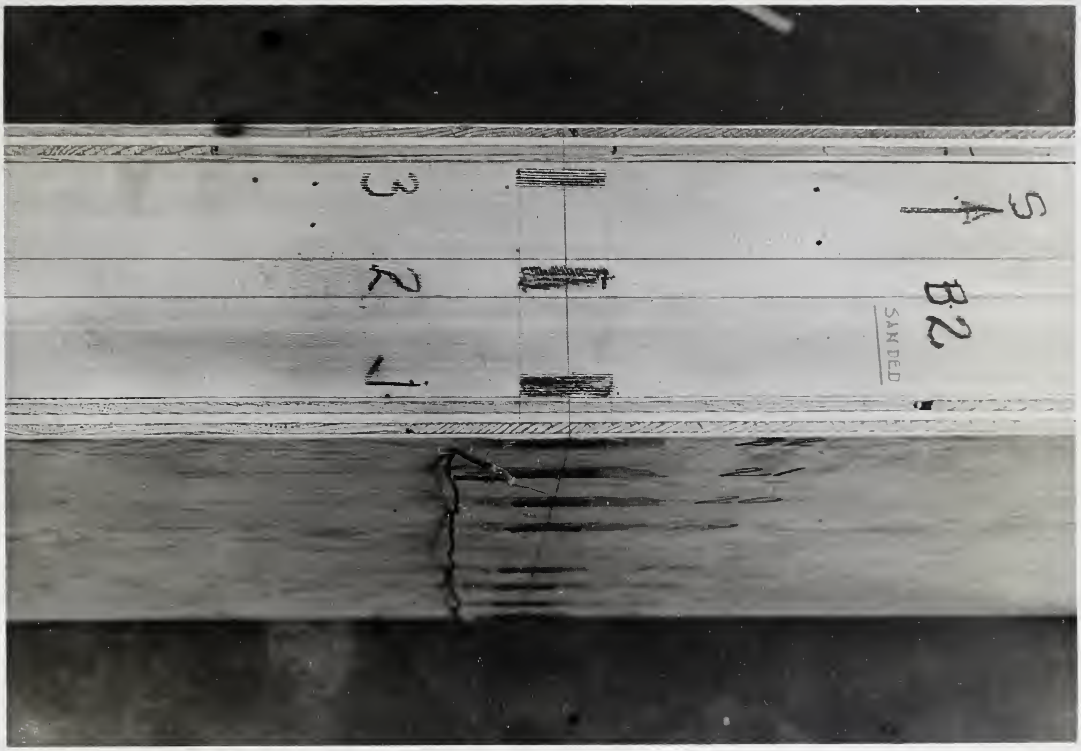
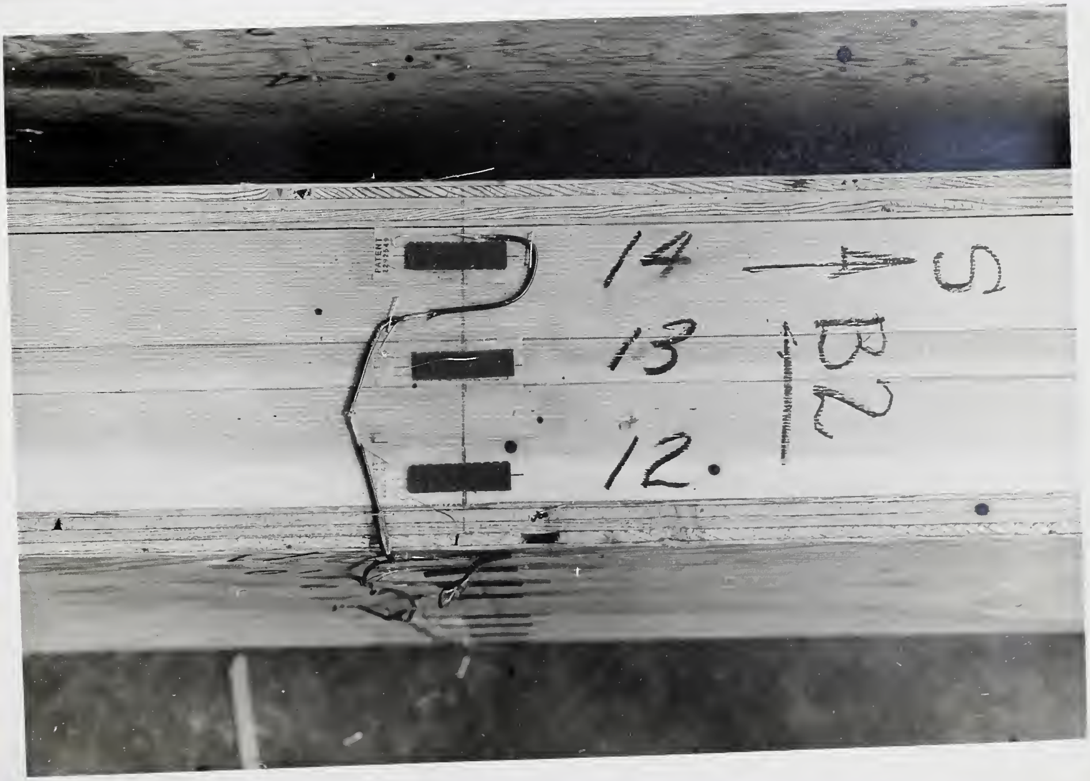
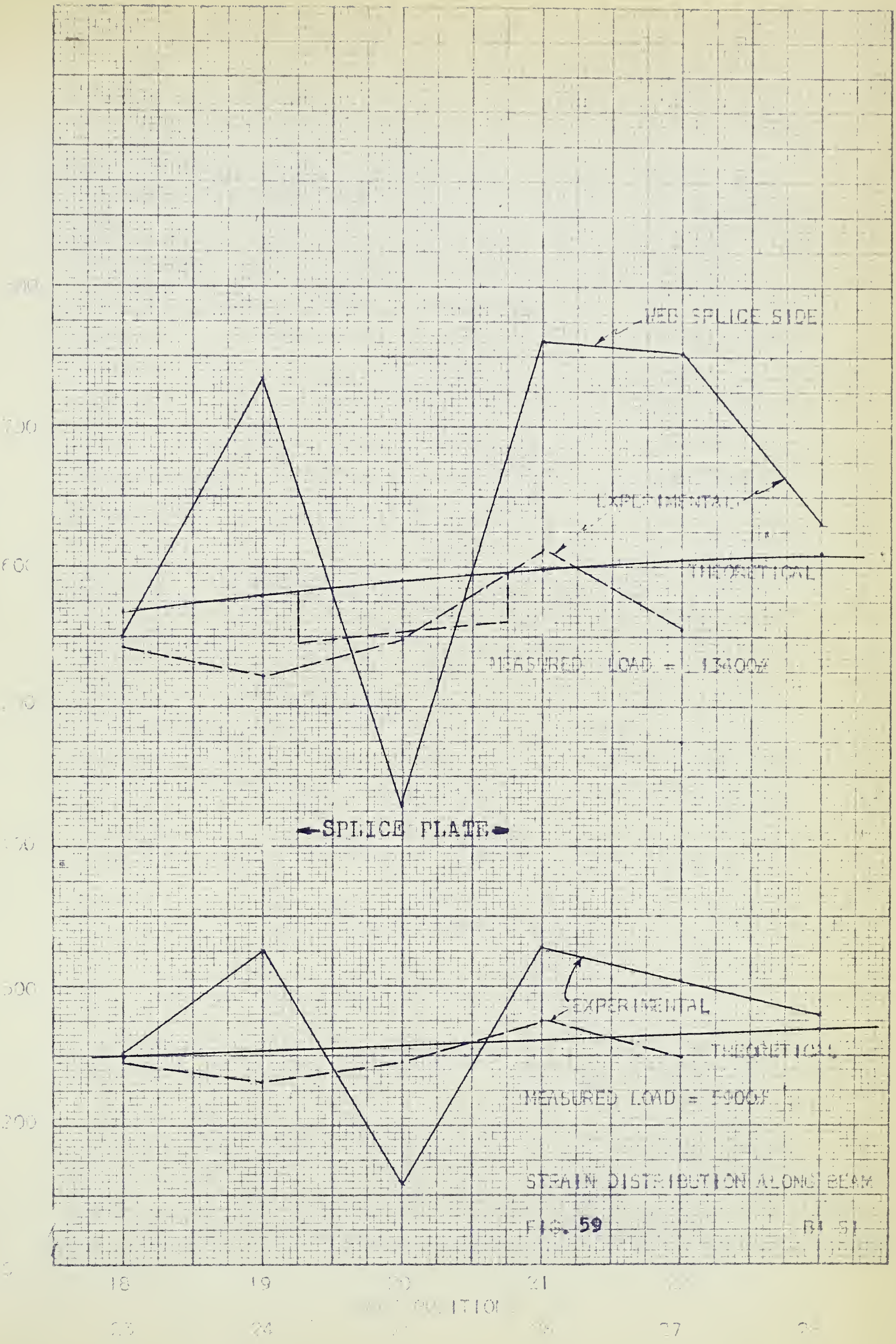


Fig. 57, Flange of Beam 2 at Gage Positions 1, 2 & 3.
Fig. 58, Flange of Beam 2 at Gage Positions 12, 13 & 14.

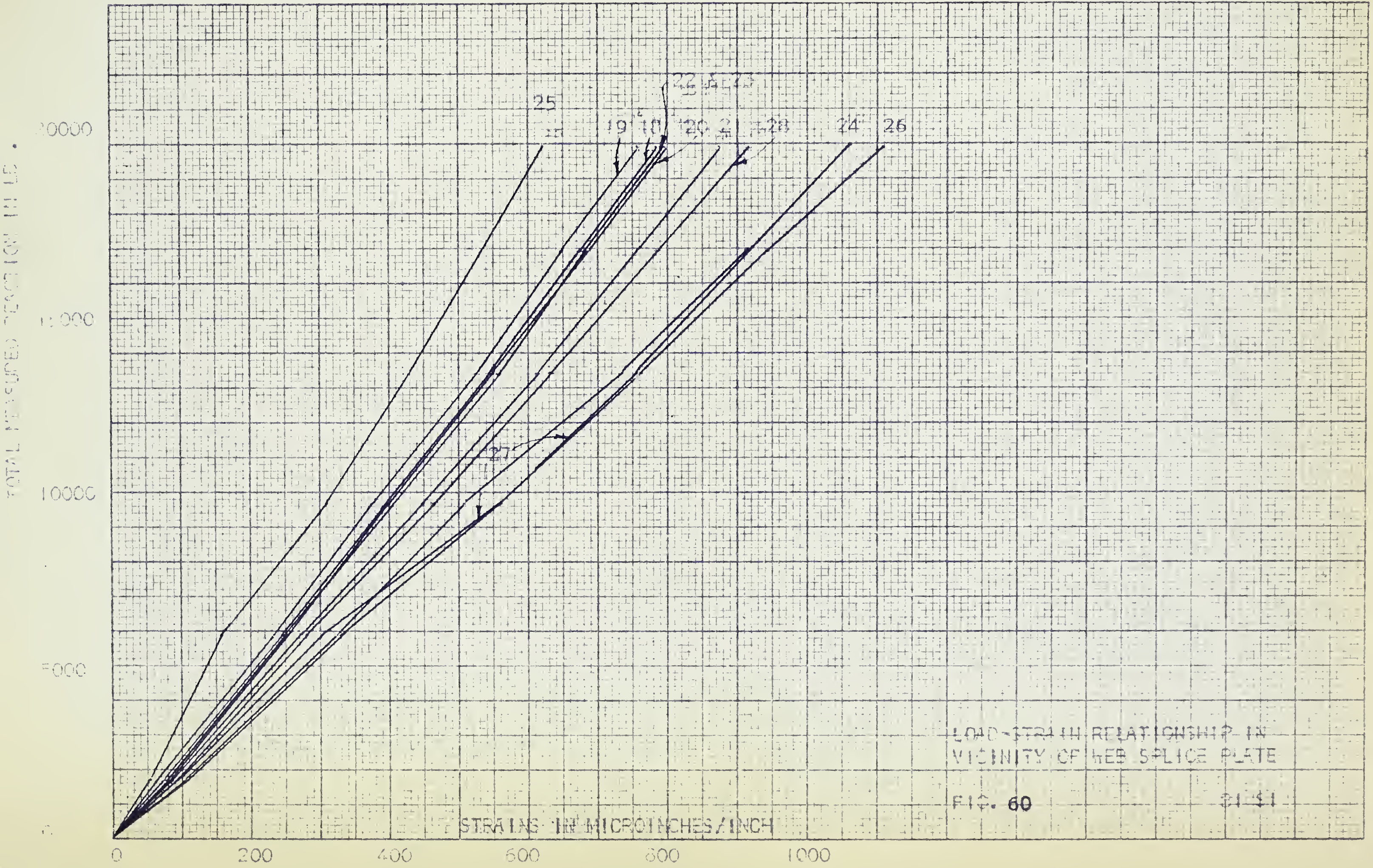




STRAIN DISTRIBUTION ALONG BEAM

FIG. 59

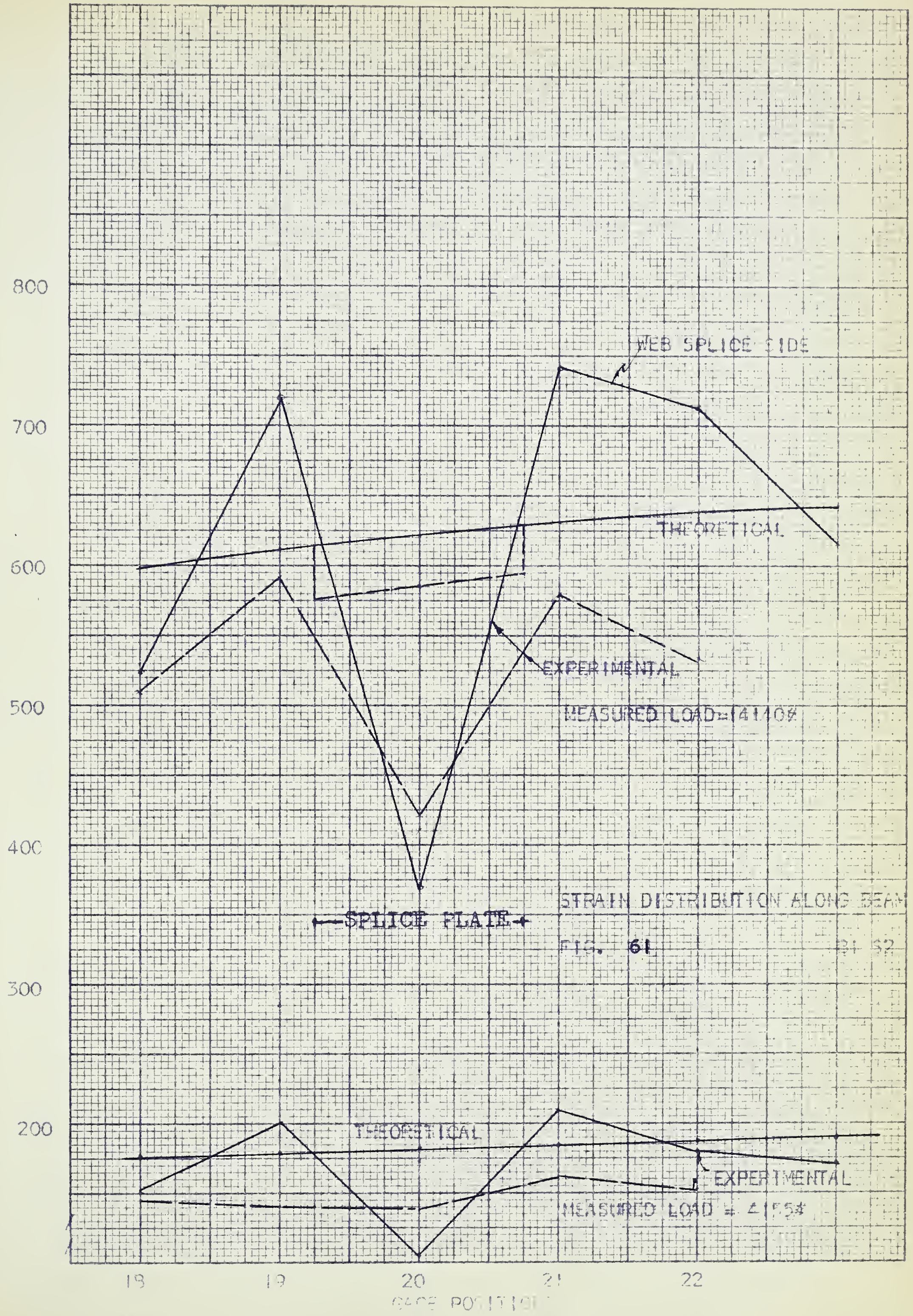
B-51



LOAD-STRAIN RELATIONSHIP IN VICINITY OF WEB SPLICE PLATE

FIG. 60

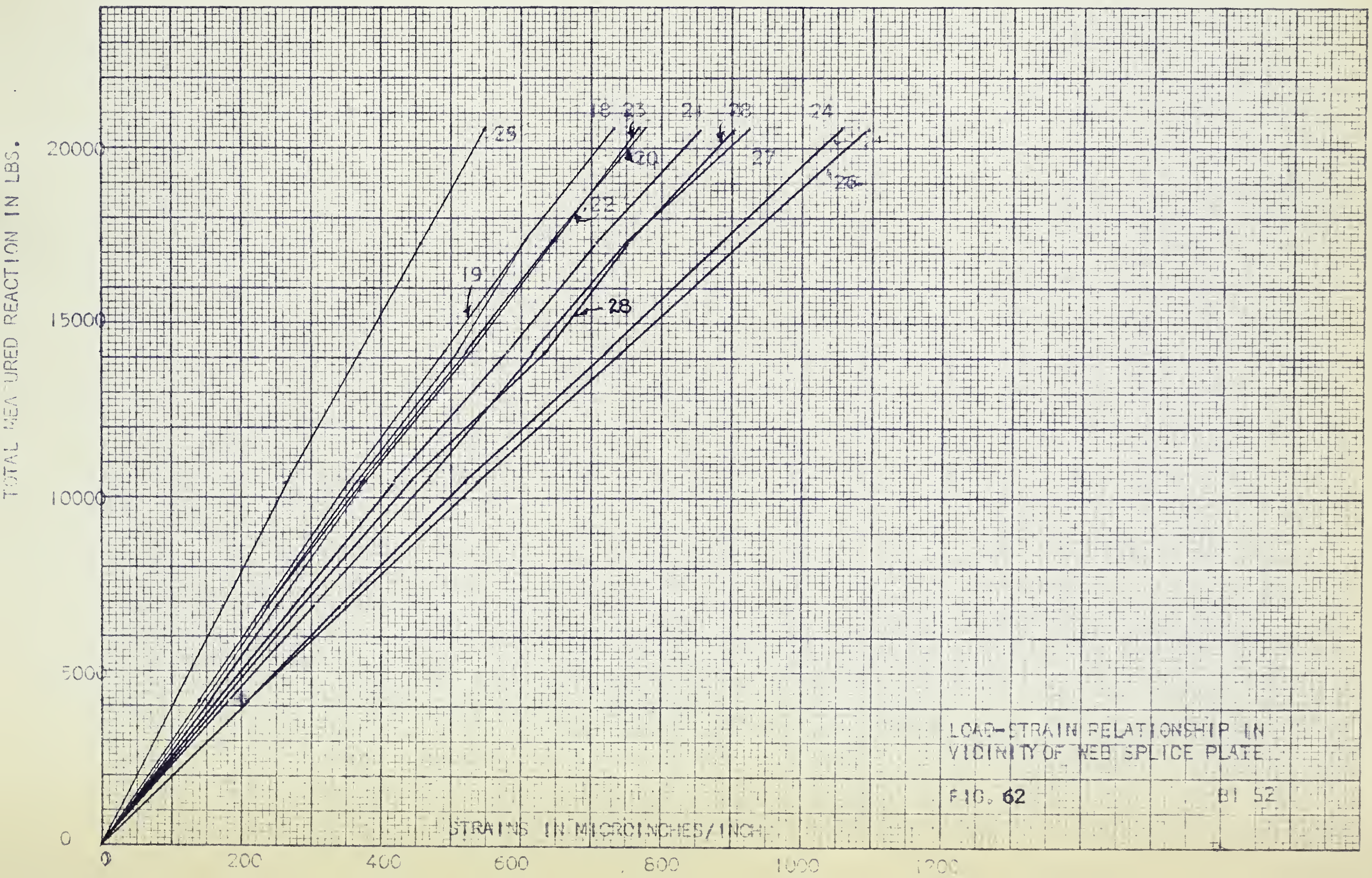
B1-S1



STRAIN DISTRIBUTION ALONG BEAM

FIG. 61

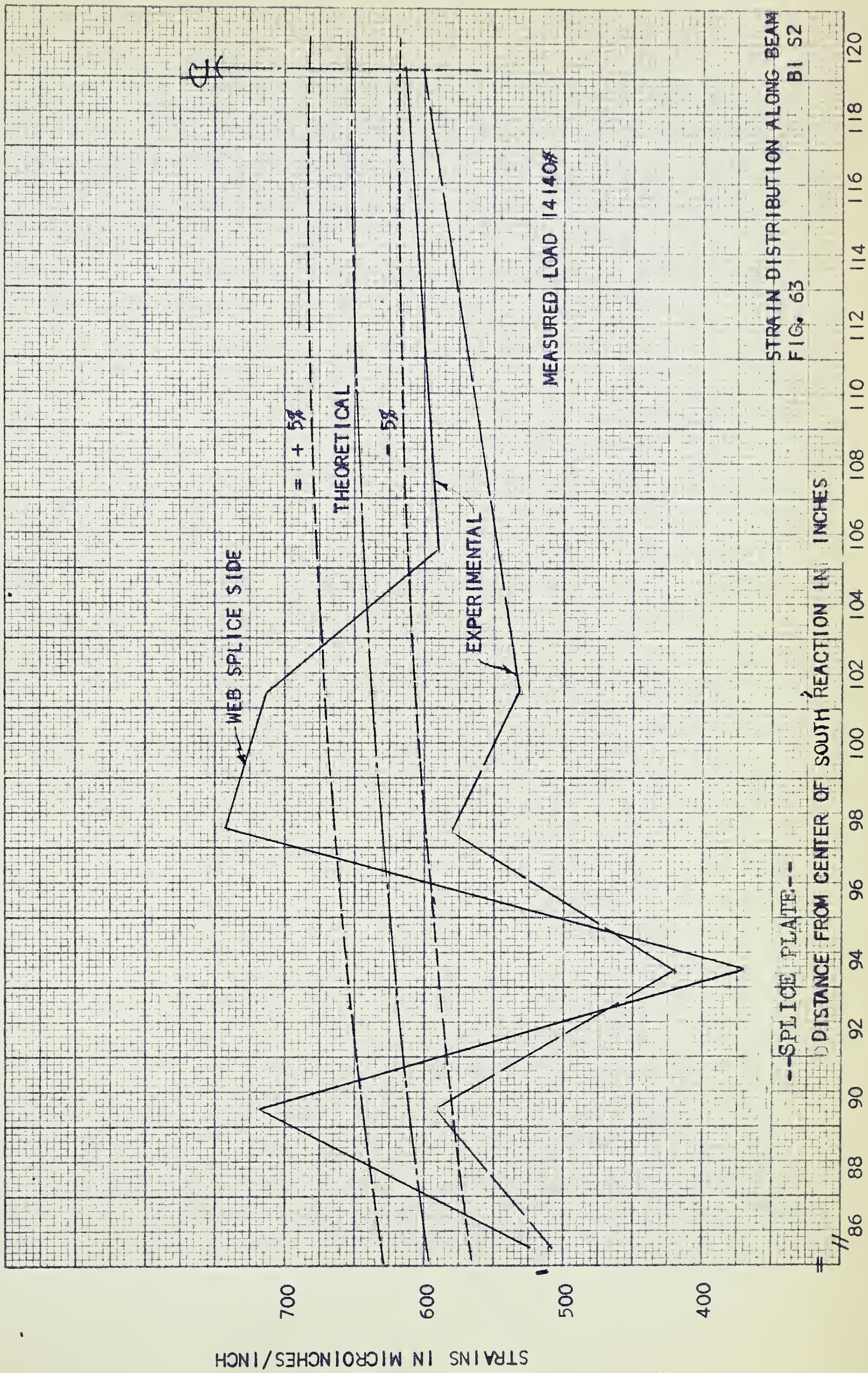
B1 S2



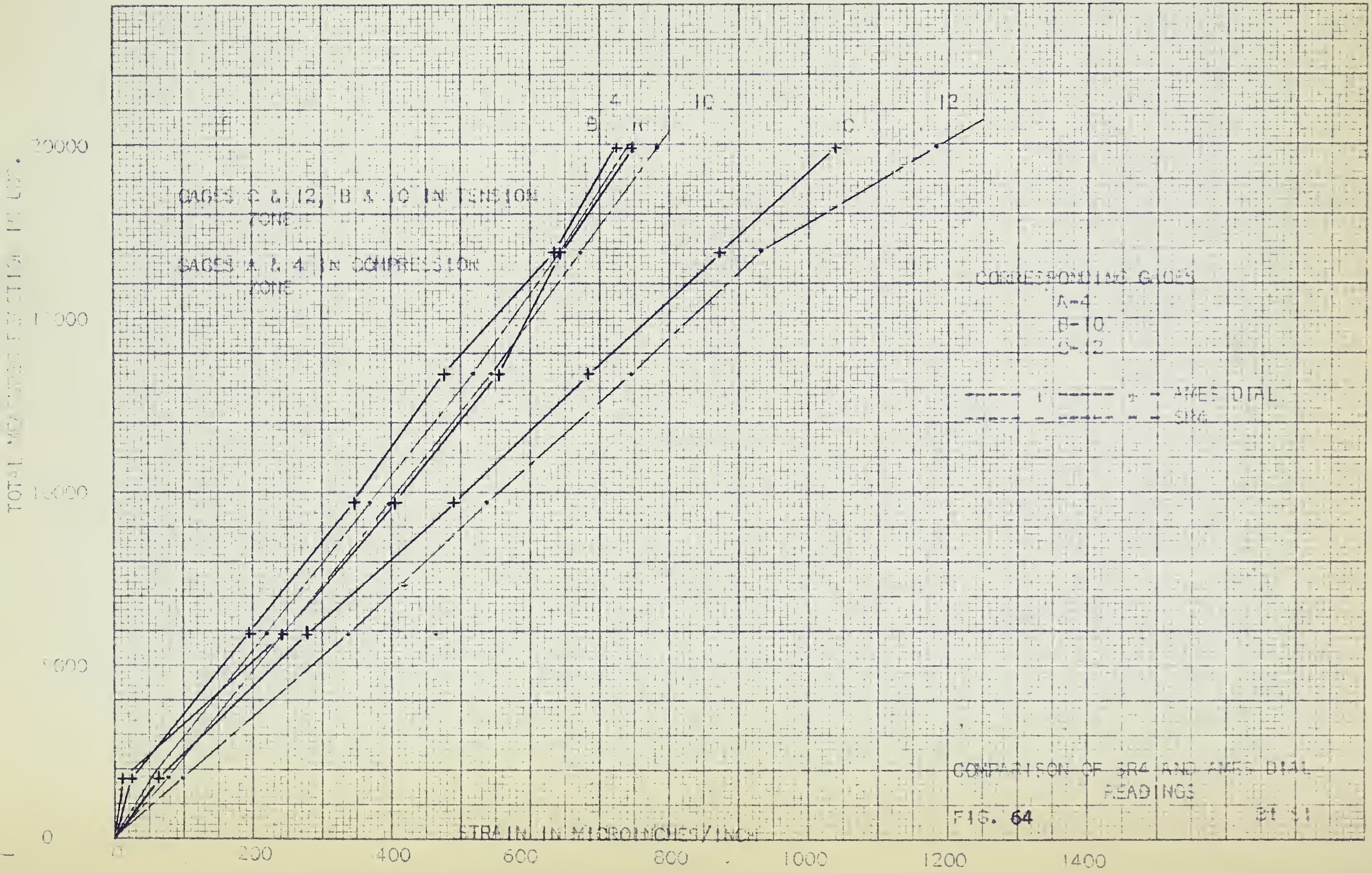
LOAD-STRAIN RELATIONSHIP IN VICINITY OF WEB SPLICE PLATE

FIG. 62

BI 52

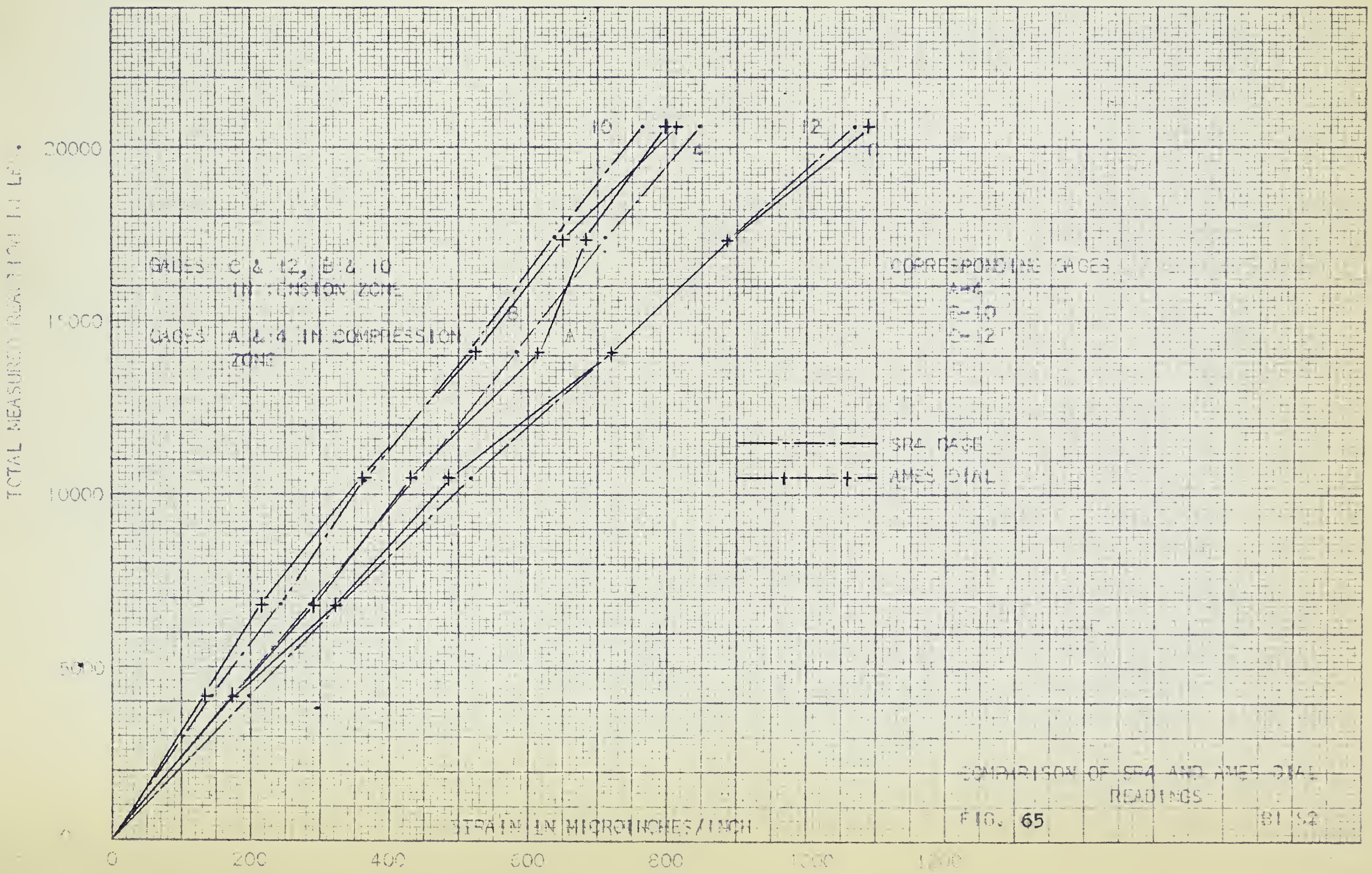


STRAIN DISTRIBUTION ALONG BEAM B1 S2
FIG. 63



COMPARISON OF SR4 AND AMES DIAL
READINGS

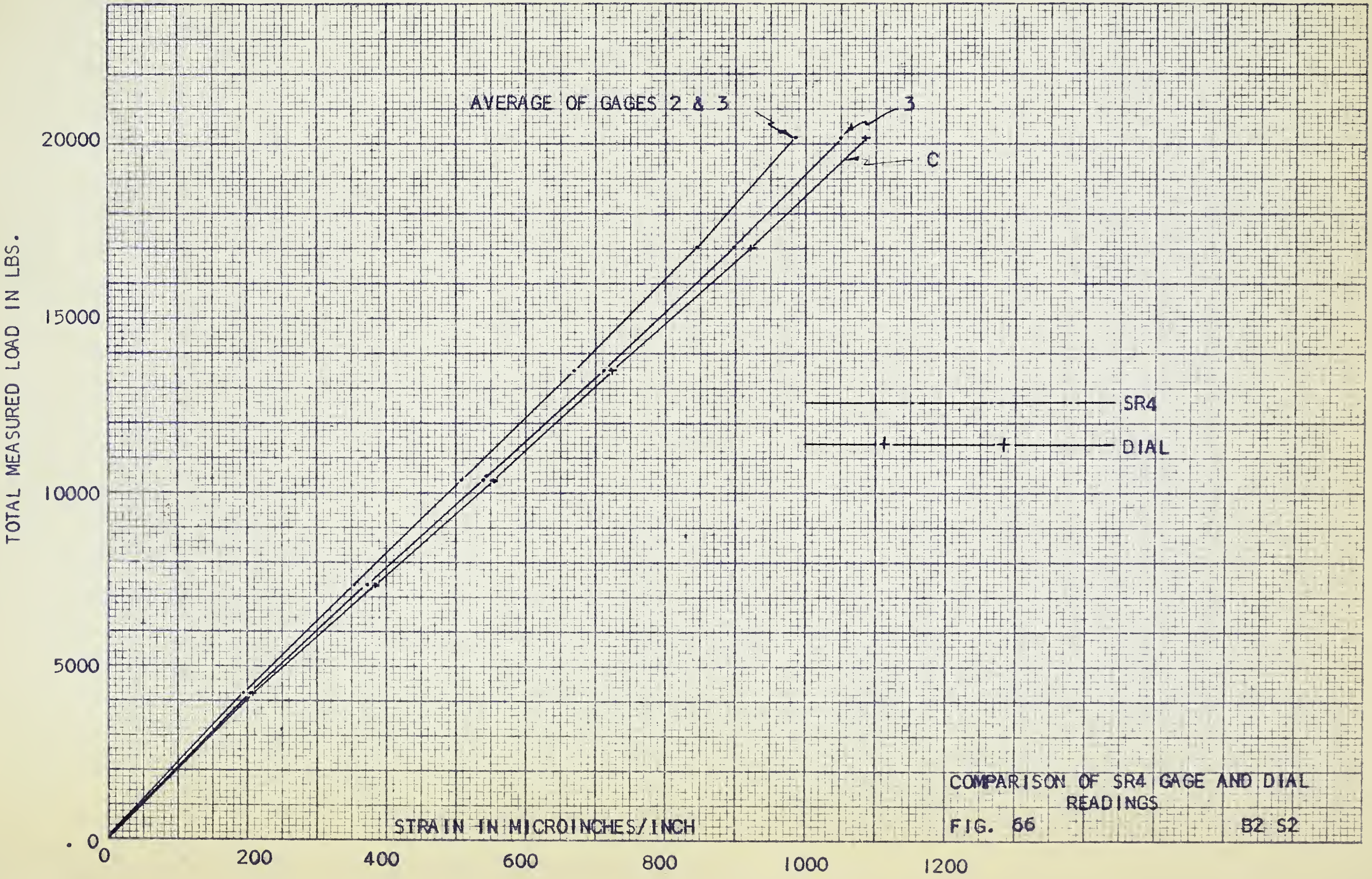
FIG. 64



COMPARISON OF SR4 AND AMES DIAL READINGS

FIG. 65

B1 S2



COMPARISON OF SR4 GAGE AND DIAL READINGS

FIG. 66

B2 S2

VI Discussion

The simultaneous loading of the beams and proving of the Line Load apparatus forced a considerable irregularity in procedure. More complications were created by the faulty switch on the strain indicator. The data for the plywood beam studies were obtained from the first few loading cycles of each beam. The 1 1/2" diameter single-gaged, 3/4" diameter single-gaged and 3/4" diameter double-gaged reaction rods were used for the first three consecutive loading cycles of beam No. 1. In the first cycle of loading of beam No. 1 loads were measured by taking the corresponding loads for air gage readings from the graph of figure 16 (load-pressure plot). Due to the difficulties with the strain indicator it was impossible to obtain an absolute measure of strain for the first cycle of loading of beam No. 2.

1. Load - Strain Relationships

In general, the load-strain relationships exhibit a practical linearity. It was shown in Part I that beyond a total load of approximately 14000 pounds for the cycles of loading during which the data for the beam studies were collected, the expansion characteristics of the pneumatic tube cause a change in load distribution. From the discussion relative to figure 25 of Part I, some curvature, though small, in the load-strain plots could be expected. However, any such curvature which is evident is not sufficiently consistent to warrant argument as to whether the intensity of load increased or decreased towards midspan.

Gages 29 to 36 located on beam No. 1 were placed opposite a shrinkage crack between the web and the flange similar to that shown in figure 31. Figures 37 and 41 show that the ratio of the flange to web strains is fairly constant but different for each pair of gages. In view of the proximity of the web splice these data are of little value.

2. Deflections

The load-deflection plots show a practical linearity. The observed midspan deflection for beam No. I at design load was 0.525 inches as compared to the computed deflection of 0.543 inches. Beam No. 2 showed a smaller deflection (0.485 inches) and these were 3.3% and 10.7% less than the theoretical value respectively. The plane distortions over the depth of the beams shown in figures 44 to 46 and 54 to 56 suggest that a greater deflection than theoretical could be expected. The observed deflections suggest that the method used for computing the deflections for short time loadings gives conservative results.

3. Strain Distribution over Depth of Beams

The plots of the strain over the depth of the beams do not clearly define the position of the neutral axes in the beams. The apparent shift of the neutral axis from the mid-depth position may be due to the distortions of the cross-sectional planes of the beams near the flanges. The distrotion is not too evident in the depth-strain plots for beam No. 2 but figure 52, which is a plot of the load-strain relationship for compression zone gages on opposite faces of beam No. 2, clearly demonstrates this. Earlier investigations on similar box beams carried out at the University of Alberta showed a fairly definite shift in the neutral axis toward the tension zone. The strains in these tests were measured on one side of the beams and this shift became marked at higher loads only. The tests on these beams were conducted immediately after their fabrication (2).

In general, for both beams (figures 44, 45, 54 and 55), the theoretical and actual strains compare favourably in the tension zones. The plane distortions, however, make it impossible to draw similar conclusions for the strains in the compression zones. Where apparently not affected by shrinkage cracks, the strain distributions over the depth

and across the flanges of the beams form approximate planes.

4. Shrinkage Effect

Strains increased considerably on the sides of the flanges opposite to the cracks. In the case of beam No. 1 the difference of strain across the flange was as much as 40% of the design load strain. The marked strain increases were on the sides of the flanges opposite the cracks shown in the photographs of figures 47, 48, 57 and 58 and can be attributed to load transfer to points where more resistance was offered. These cracks developed in the first and second plies adjacent to the flange material in beams No. 2 and No. 1 respectively. The distortions produced by the crack in the second ply were much more marked.

Although the recorded moisture content of the plywood at the time the beams were fabricated appears to be excessively low (The average plywood moisture content in the Edmonton area is 5 to 8%.)(3), the problem of differential shrinkage will always exist where the beams are put to service under varying atmospheric conditions. The ratio of the coefficients of shrinkage for solid wood and plywood is roughly 20 to 1(4). In order to eliminate the differential shrinkage effects between the two materials it would be necessary to assemble both materials when they were simultaneously in equilibrium with respect to the atmosphere and to maintain these conditions or those within tolerable limits for the service life of the beams. E. G. Bergin suggests differential shrinkage effects as a cause of glue joint failures(5). He further suggests that wood should be seasoned to within 7 to 12% moisture content for use with casein glue(6). Although it was suggested that moisture content differences up to 5% are tolerable for gluing 2 pieces of the same type of wood together(7), no similar information could be found for solid wood and plywood.

5. Web Splice

Figures 59 to 63 indicate that strains in the vicinity of the web splice are as much as 25% greater than the theoretical strains at design load. The linearity of the load-strain plots of figures 60 and 62 indicate that the strains are approximately in the same proportions for all those loads that were measured in these tests.

6. Comparison of SR-4 and Mechanical Dial Readings of Strain

It must be borne in mind that strains from the dial readings are averages over an 8 inch gage length whereas the SR-4 readings are averages over a 1 inch gage length. Dial C demonstrates the best comparison. The dials were not serviced before use. However, dial C was in continuous use in the machine shop previous to use in these tests and its better performance is understandable. Although the graphs of figures 64, 65 and 66 indicate that the mechanical gages experienced starting difficulties, the fact that the plots for both types of instruments are approximately parallel indicates that the measured strain increments were practically the same.

VII Conclusions

1. The strain distributions over the midspan cross-sections of the beams were seriously affected by the cracks in the plywood webs near the flanges. These cracks were attributed to the effects of the differential shrinkage between the solid flange material and the plywood webs. Up to 40% variations of strain across the flanges were observed at midspan when the beams were loaded with their design load.

2. The observed strains in the area of the web splice were as much as 25% greater than the calculated strains.

3. The strains observed using the SR-4 electric strain gages compared favourably with those strains observed using the 0.0001" mechanical dials on 8 inch gage lengths.

4. The total observed design load deflections due to bending and shear were 3.3% and 10.7% (Beam Nos. 1 and 2 respectively) less than the calculated deflections. The deflection due to bending was calculated using the average net moment of inertia of the beam and a modulus of elasticity of 1.6×10^6 pounds per square inch for the flange and web materials. The deflection due to shear was calculated using the average gross moment of inertia of the beam and a modulus of rigidity of 117,000 pounds per square inch for the plywood web material.

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